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An Experimental Investigation on the Mechanical Properties of Bottom Ash Concrete

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Abstract

In this research Quarry (manufactured) sand is used as hundred per cent substitutes to the river sand. Pozzolona Portland Cement was replaced by silica fume (10% by weight) and hyperplasticizer with varying percentage by weight of binder was added to obtain medium workability. In modern thermal power plants, 20% of ash is fed into the bottom of boilers. To solve the problem of the bottom ash disposal from the power plant, the investigations were carried out for the possibility of using bottom ash as partial replacement (10% - 50%) of manufactured sand (M-Sand) in concrete. Mechanical properties, such as compressive strength, split tensile strength, flexural strength and modulus of elasticity of M60 concrete (Grade of mix 60N/mm^2) were evaluated. The result showed that use of bottom ash improves the strength of concrete at later ages.

Keywords: Bottom Ash, High-Range Water Reducers, Manufactured Sand, Pozzolana Portland Cement, Silica Fume, Strength

1. Introduction

Fine aggregate is an important and essential ingredient of concrete. River sand is most commonly used as fine aggregate in concrete. The scarcity of river sand affected the growth of construction industry. As an alternative, the waste materials after the extraction of coarse aggregate in stone quarries were used as Fine aggregate. The processing of the waste rocks to form fine particles less than 4.75 mm is called as manufactured sand (M-Sand). Concrete with crushed sand as fine aggregate requires an increase of super plasticizer to obtain the same slump of concrete with river sand as fine aggregate[1]. The compressive strength, split tensile strength and flexural strengths of concrete are not affected with the replacement of sand by Crushed rock powder as fine aggregate up to 40% without any mineral admixtures[2]. M-Sand with more roughness, low crushing value and good abrasion resistance is suitable for producing high quality concrete. Natural rough and angular characteristics of M-Sand particles are generally superior to River sand-Pavement cement concrete in flexural strength and abrasion resistance[3]. Super plasticizer with varying percentage was used to get the medium workability of fresh concrete with M-Sand. Carboxylic base super plasticizer was of higher performance than the other types. Higher decrease in water cement ratio (w/c) was achieved in mixtures with crushed aggregates by the use of hyperplasticizer (Carboxylic base)[4]. Nowadays, Ordinary Portland Cement (OPC) was substituted by Pozzolana Portland Cement (PPC) due its more performance. The strength of OPC has been reduced in textile waste water exposure and is due to presence of more CaO in OPC than PPC leads to leaching[5]. Use of mineral admixtures generally increases the strength and performance of concrete. Cement replacement up to 12% with silica fume leads to increase in compressive strength, split

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tensile strength and flexural strength for both M40 and M50 grades[6]. The compressive strength of concrete with 10% silica fume and 1% Nano Silicon Dioxide replacement in cement increase about 42.2% than the control mix[7]. Bottom ashes from thermal power station are normally disposed of either dry or wet to an open area. This causes the pollution in nearby water bodies and also decreases the productive land area. This paper represents the effective use of bottom ash in concrete. The strength of concrete with fine aggregate (river sand) replaced with bottom ash continue to increase with age for all the bottom ash contents[8]. The mechanical properties of concrete with washed bottom ash replacement with natural sand is found to good gain in strength over the increases in concrete age[9]. The compressive strength of concrete mixed with fly ash and bottom ash is increased at later age of concrete[10]. The concrete compressive strength with higher cement paste is not strongly affected by the replacement of washed bottom ash[11]. In this study the effect of Bottom ash in concrete were investigated for mass laying of high strength with pumpable property. The mechanical properties were studied with partial replacement of M sand with bottom ash of 10%, 20%, 30%, 40% and 50%.

2. Experimental Program

2.1 Materials

2.1.1 Cement

Portland Pozzolana Cement conforming to IS 1489 (Part 1): 1991[12] of specific gravity 3.12, initial and final setting time of 45 minutes and 485 minutes respectively was used.

2.1.2 Silica Fume

Silica fume of grade 920-D obtained from Elkem India private limited, Mumbai, India was used as mineral admixture.

2.1.3 Fine and Coarse Aggregates

Manufactured sand (M-Sand) from locally available Quarry industry conforming to IS 383:1970 and IS: 2386 (Part 3)[13,14] of specific gravity 2.8 and fineness modulus 2.6 was used as fine aggregate. Crushed aggregate (20 mm size) of specific gravity 2.74 conforming to IS 383:1970[13] was used as coarse aggregate.

2.1.4 Bottom Ash

Bottom ash obtained from thermal power plant at Erode, Tamil Nadu in India of 49% SiO_2 and 25.7% Al_2O_3 as chemical composition was used in this studies. Sieve analysis results in percentage were shown in Table 1.

Table 1. Seive analysis

Sieve Size	M-Sand	Bottom Ash
4.75 mm	100	100
2.36 mm	100	95
1.18 mm	80	87
600μm	43	71
300μm	8	20
150μm	9	9

2.1.5 Super Plasticizer

A polycarboxylic acid based superplastizicer commercially available as cera hyperplast was used at varying percentage by weight of binder to maintain medium workability as per IS 456 - 2000[15].

2.2 Mix Proportions

Concrete mixtures were calculated as shown in Table 2. The control mix of grade M60 without bottom ash (BA 0) was designed as per Indian standard specification IS 10262-2009[16]. The specimen were tested at age of 7, 28, 56 days as per IS 516-1959[17] (partial replacement of M sand with bottom ash of 10%, 20%, 30%, 40% and 50%) to evaluate the usage of bottom ash in concrete.

2.3 Experiment Method

2.3.1 Workability

The degree of workability of concrete (slump test) was maintained as medium value (75 mm to 100 mm) as per clause 7 of IS 456 - 2000 by varying the percentage of super plasticizer.

2.3.2 Compression Strength

Compressive strength of concrete was determined on cubes (72 nos) of size 150 mm x 150 mm x 150 mm at the age of 7, 28, 56 and 90 days using Compression Testing Machine (CTM) of capacity 4000 kN as per IS:516 - 1959.

Table 2. Mix proportions per m^3

Mix ratios	SF%	Silica fume [kg]	Cement [kg]	BA%	Bottom Ash [kg]	F.A. [kg]	C.A. [kg]	Super plasticizer %	Water [litre]
BA 0 (Control mix)	10	43.59	392.34	0	0	672.34	1238	0.8	139.5
BA10	10	43.59	392.34	10	67.24	605.1	1238	1.0	139.5
BA20	10	43.59	392.34	20	134.46	537.87	1238	1.2	139.5
BA30	10	43.59	392.34	30	201.7	470.63	1238	1.6	139.5
BA40	10	43.59	392.34	40	268.13	403.4	1238	2.0	139.5
BA50	10	43.59	392.34	50	336.17	336.17	1238	2.4	139.5

2.3.3 Split Tensile Strength

Split tensile strength of concrete was determined on cylinder (72 nos) of size 150 mm x 300 mm at the age of 7, 28 and 56 days using CTM as per IS:5816 - 1999[18].

2.3.4 Young's Modulus

Young's modulus of concrete was determined on cylinder (18 nos) of size 150 mm x 300 mm at the age of 28 days using Universal Testing Machine (UTM) as per IS:516 - 1959. AS per IS 456 - 2000 ,the elastic modulus of concrete was determine based on compressive strength of concrete.

2.3.5 Flexural Strength

Flexure tensile strength of concrete was determined on prism (36 nos) of size 100 mm x 100 mm x 500 mm at the age of 28 and 56 days using UTM as per IS:516 - 1959.

3. Results and Discussion

3.1 Mechanical Properties

3.1.1 Workability

The workability of concrete mixture was decreased when M sand was replaced with bottom ash. The slump value was decreased with addition of BA as fine aggregate[11]. In this research the slump value was decreased from 100 mm (without BA) to 80 mm (10% BA). The slump was maintained as constant value 80 mm to get the medium workability as per IS 456 - 2000. (50 mm to 100 mm for heavily reinforced concrete and 75 mm to 100 mm for pumped concrete).

At fixed slump value, at all the test ages when fine bottom ash was used as fine aggregate to replace natural aggregate, the concrete had higher compressive strength[19].

3.1.2 Compression Strength

The test result of compressive strength with bottom ash as partial replacement in concrete was shown in Table 3. The compressive strength of 90 days curried bottom ash (BA 10) concrete was almost equal to the target strength of concrete without bottom ash. The bottom ash concrete gain strength at a slower rate in initial period and attains strength at faster rate beyond 28 days. At early age BA reacts slowly with calcium hydroxide liberated during hydration of cement and does not contribute significantly to the densification of concrete at early ages[8]. The bottom ash up to 20% replacement, the strength was increased approximately 50% at the age of 90 days[10]. The above result was conformed in this research that the compressive strength (BA 10) at age of 90 days was increased almost equal to 50% of 7 days strength. The concrete sam-

Table 3. Compressive strength and Split tensile strength results

MIX	Compressive Strength				Split Tensile Strength			
	7 Days MPa	28 Days MPa	56 Days MPa	90 Days MPa	7 Days MPa	28 Days MPa	56 Days MPa	90 Days MPa
BA 0	51.45	69.89	73.24	78.45	3.92	4.54	5.82	6.12
BA 10	45.35	57.56	67.54	69.74	3.63	4.13	5.54	5.95
BA 20	40.12	56.68	61.04	64.41	3.40	3.99	5.37	5.80
BA 30	35.32	54.06	59.29	63.02	3.22	3.74	5.05	5.45
BA 40	34.88	53.62	57.12	62.34	3.10	3.59	4.89	5.12
BA 50	30.52	47.96	51.45	62.01	2.90	3.17	4.30	4.84

ples having 20% sand replaced with pond-ash showed improved compressive strength over the control sample at all the curing ages[20,21].

After 90 days of curing age, compressive strength of bottom ash concrete mixtures (BA 10) exceeded by 17.46% of their 28 days compressive strength as compared to an improvement of 10.91% over 28 days compressive strength by the control concrete mix (BA0). The previous study also shows same effect on bottom ash replacement in concrete[22].

3.1.3 Split Tensile Strength

The indirect tensile strength of bottom ash concrete was shown in Table 3. The split tensile strength of concrete decreases with the increase of bottom ash percentage and also the indirect tensile strength of bottom ash concrete increases with the age of concrete8. In this research also the gain in bottom ash strength was increased at the later ages. In early days the split tensile strength of concrete with fly ash and other mineral admixtures was low[23].

3.1.4 Young's Modulus

The elastic strength of bottom ash concrete was shown in Table 4. The modulus of elasticity of concrete without BA was 38.7 GPa at 28 curing. Its value decreased to 33.43 GPa (13.7%) when BA was replaced at 50%. When 100% sand was replaced with fine bottom ash, the modulus of elasticity of concrete decreased by from 41.1 GPa to 34.9 GPa[11]. The modulus of elasticity of concrete at 28 curing age, decreased from 25.8 GPA to 8.9 GPa when the replacement ratio of bottom ash increased to 100%[24]. In this research also, the BA replacement affects the elastic behavior of concrete.

Table 4. Young's modulus and Flexural strength results

MIX	Young's Modulus	Flexural Strength	
	28 Days MPa	28 Days MPa	56 Days MPa
BA 0	38.73	5.7	7.32
BA 10	37.14	5.59	7.21
BA 20	35.9	5.45	7.12
BA 30	35.2	5.31	6.86
BA 40	34.5	5.22	6.56
BA 50	33.43	4.98	6.50

3.1.5 Flexural Strength

Flexural strength of bottom ash concrete decreased with increase in bottom ash content but with the addition of super plasticizer, it slightly improved at almost all the curing ages[25]. In this study also the flexural strength of concrete decreases with increase in bottom ash (Table 4). The bottom ash concrete gains flexural strength with the age that is comparable but less than that of control concrete (BA0)[8]. In this research the flexural strength of control concrete were 5.7 MPa and 7.32 MPa at 28 days and 56 days respectively. The decrease in flexural strength for BA50 was 12.6% and 11.2% at 28 days and 56 days respectively. The coal bottom ash mixing ratio increased the degree of flexural strength reduction[10]. In these studies the flexural strength of concrete for BA 40 and BA 50 at 56 days was almost equal.

4. Conclusion

To use the coal ash waste (Bottom ash) as partial replacement for manufactured sand in concrete, in this study the mechanical properties were analyzed, based on the results and discussion the following conclusion may be drawn:

- The flow characteristics (slump value) of manufactured sand concrete (BA 0) was reduced slightly while fine aggregate was replaced with BA. The slump value was maintained as 80 mm to pump the concrete by adding super plasticizer in varying percentage.
- The compressive strength of Bottom ash concrete was low at early age and at the age of 90 days, the compressive strength of BA10 was equal to the target compressive strength (BA 0, 28 days). There was no much variation in compressive strength when M-Sand was replaced with Bottom ash at later ages.
- The split tensile strength of Bottom ash concrete was slightly decreased when M-Sand was replaced with Bottom ash. But the tensile strength increases with increase in concrete age. The split tensile strength of BA 10 at 90 days was greater than BA 0 at 28 days and 56 days.
- The percentage reduction of modulus of elasticity for BA 10, BA 20 and BA 30 were 96%, 93%, 91% when compared to BA 0.
- At 56 days curing, the flexural strength of bottom ash concrete of all the replacements BA10, BA20, BA30, BA40 and BA50 were greater than the 28 days curing strength.
- Comparatively the bottom ash replacement (Mix BA 10) can be used in concrete to effectively use the bottom ash disposal from thermal power station to avoid land pollution.

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