IMPACT: International Journal of Research in Engineering & Technology (IMPACT: IJRET)
ISSN(E): 2321-8843; ISSN(P): 2347-4599
Vol. 2, Issue 9, Sep 2014, 111-122

STRENGTH PERFORMANCE OF CONCRETE USING BOTTOM ASH AS FINE AGGREGATE

REMYA RAJU[1], MATHEWS M. PAUL[2] & K. A. ABOOBACKER[3]

[1]Post Graduate Student, Department of Civil Engineering, Mar Athansius College of Engineering, Kothamangalam, Kerala, India

[2]Professor, Department of Civil Engineering, Mar Athansius College of Engineering, Kothamangalam, Kerala, India

[3]Consultant, Structural Engineer, Structural and Foundation Engineer, Kochi, Kerala, India

ABSTRACT

Concrete is the most important engineering material and the addition of some other materials may change the properties of concrete. Studies have been carried out to investigate the possibility of utilizing a broad range of materials as partial replacement materials for cement and aggregate in the production of concrete. The present experimental study was conceived following the general purpose of testing new sustainable building processes and modern production systems, aims not only at saving natural raw materials and reducing energy consumption, but also to recycle industrial by-products. The objectives of this study was to investigate the effect of use of coal bottom ash as partial replacement of fine aggregates in various percentages (0–30%), on concrete properties such as compressive strength, spiltting tensile strength test, flexural strength and modulus of elasticity and also the effect of microsilica in bottom ash concrete having maximum compressive strength. The test results of this research work indicates that at fixed water cement ratio, workability decreased with the use of coal bottom ash as a replacement of fine aggregate in concrete. Compressive strength of bottom ash concrete at the curing age of 28 days was increased compared to control concrete. Splitting tensile strength of concrete improved at percentages of replacement of bottom ash. The modulus of elasticity decreased with the use of coal bottom ash at all replacement levels.

KEYWORDS: Coal Bottom Ash, Concrete, Compressive Strength, Splitting Tensile Strength, Flexural Strength, Modulus of Elasticity

INTRODUCTION

Concrete is the most vital material for the construction of high rise buildings and various infrastructures. Infrastructure development in such areas particularly in developing countries like India is more. Concrete is a mixture of cement, fine aggregate, coarse aggregate and water and river sand is the main raw material used as fine aggregate in the production of concrete. The natural sources of river sand are getting depleted gradually. The demand for the protection of the natural environment and the ban on mining in some areas is further aggravating the problem of availability of river sand. At present, the construction industry is plagued with the scarcity of this essential constituent material of concrete. Therefore, in the present circumstances of scant sources of river sand and boom in infrastructure development, it becomes essential and more significant to find out its substitute material in concrete.

Coal bottom ash is a coarse granular and incombustible byproduct from coal burning furnaces. It is composed of mainly silica, alumina and iron with small amounts of calcium, magnesium sulfate, etc. The appearance and particle size distribution of coal bottom ash is similar to that of river sand. These properties of coal bottom ash make it attractive to be used as fine aggregate in the production of concrete.

Singh and Siddique [1] also reported that coal bottom ash is the potentially viable material to be used as fine aggregate in the production of concrete. The previous studies in which coal bottom ash has been targeted as a substitute for sand in production of concrete demonstrate that the strength development pattern of coal bottom ash concrete is similar to that of conventional concrete. Aggarwal et al. [4] reported that the workability in terms of compaction factor, compressive strength and splitting tensile strength decreased on use of pond ash as replacement of sand in concrete. A research was conducted by Abdulhameed et al. [5] on properties of concrete using tanjung bin power plant coal bottom ash and fly ash. Coal bottom ash and fly ash were utilized in partial replacement for fine aggregates and cement respectively in the range of 0, 5, 10, 15 & 20% (equal percentages). Their results showed that for a grade M35 concrete with a combination of coal bottom ash and fly ash can produce 28 day strength above 30MPa. They concluded that the use of coal bottom ash and fly ash in concrete has the potential to produce long term durable and good strength concrete.

M. P. Kadam and Dr. Y. D. Patil [6] were studied the effect of coal, bottom ash as sand replacement on the properties of concrete with different w/c ratio. They concluded that upto 30% replacement of bottom ash, the compressive strength, split tensile strength and flexural strength increased for all 7, 10 14, 28, 56 and 90 days of curing. A study was conducted by P. Tang et al. [7], on the application of Municipal Solid Waste Incineration (MSWI) bottom ash fines in high performance concrete they concluded that the concrete porosity increases with increase of bottom ash fines. The compressive and flexural strength of concrete decrease with the increase of the bottom ash fines at the same curing age, especially after 3 and 7 days. Yogesh Aggarwal and Rafat Siddique [8], were studied microstructure and properties of concrete using bottom ash and waste foundry sand as partial replacement of fine aggregates.

They concluded that the mechanical behavior of the concrete with fine aggregate replacements was comparable to that of conventional concrete except for 60% replacement. The inclusion of waste foundry sand and bottom ash as fine aggregate does not affect the strength properties negatively as the strength remains within limits except for 60% replacement. A study was carried out in 2013 by PG scholar C Mathiraja [9], on concrete using bottom ash, manufacturing sand and hybrid steel and coir fibers. The inclusion of fibers into concrete not only provides considerably more ductile structure but also improves such structural properties as tensile strength, static flexural strength, impact strength, flexural toughness and the energy absorption capacity of the high strength concrete. The research work carried out by Kim and Lee [10] indicates that the compressive strength of concrete mixtures made with coal bottom ash as a substitute for sand was not strongly affected. However, flexural strength and modulus of elasticity of concrete decreased with the increase in the content of coal bottom ash.

The value of the current research is the use of coal bottom ash as fine aggregate. The mineral admixture used in this study was microsilica, which is extracted from exhaust gases of silicon and ferrosilicon smelting furnaces and utilized in concrete to improve the properties of the concrete. The main purpose of incorporating the material in concrete is to make use of the very fine and reactive particles to produce a denser cement matrix. The microsilica particles have a pozzolanic reaction with calcium hydroxide from the hydration of the cement, thereby increasing the total product of hydration and reducing the amount of calcium hydroxide. When properly used, microsilica decreases the permeability of the concrete providing a more durable and more sustainable product. A small quantity of microsilica can be effective in a concrete mix, a typical dosage being in the range 5 to 10% by weight of the cement.

The objectives of this study are to investigate the effect of use of bottom ash as partial replacement of fine aggregates in various percentages (0–30%), on concrete properties such as compressive strength, workability, flexural strength etc. and also the determine the optimum dosage of microsilica in bottom ash concrete having maximum compressive strength. The present experimental study was conceived following the general purpose of testing new sustainable building processes and modern production systems, aims not only at saving natural raw materials and reducing energy consumption, but also to recycle industrial by-products. Utilization of coal combustion products in construction industry is an important issue involving reduction in technical and economical problems of plants, besides reducing the amount of solid wastes, greenhouse gas emissions and conserving existing natural resources.

MATERIALS AND METHODS

Materials

Ordinary Portland Cement (53 MPa) conforming to relevant Indian standard specifications [11] with consistency as 35% and specific gravity as 3.15 was used. M sand with 4.75 mm maximum size was used as fine aggregate, fulfilling the requirements of IS:383-1970 [13] along with crushed stone of 20 mm maximum size used as coarse aggregate. The particle size distribution fine aggregate was shown in Figure 1. The physical properties of fine aggregate and coarse aggregate was tabulated in Tables 1 and 2 respectively. Coal bottom ash obtained from Hindustan Newsprint Limited, Kottayyam, Kerala, India was used as partial replacement of fine aggregates. The coal bottom ash was screened to remove the oversized particles and the material passing through 4.75 mm sieve was used in manufacturing of concrete. The chemical and physical properties of coal bottom ash used in this research are given in Tables 3 and 4 respectively. The chemical analysis shows that coal bottom ash is mainly composed of silica and alumina. The particle size distribution of bottom ash used in this investigation was shown in Figure 2. Microsilica for the present investigation was supplied by BSS Pvt. Ltd at Cochin, Kerala. The superplasticizer used in this present investigation was Master Rheobuild 1125 manufactured by BASF Chemicals Pvt. Ltd.

Table 1: Physical Properties of Fine Aggregate

Sl. No.	Properties	Value
1	Specific gravity	2.66
2	Water absorption	12 %.
3	Fineness modulus	3.12
4	Grading Zone	Zone II

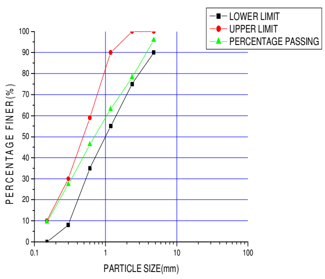

Figure 1: Grading Curve of Fine Aggregate

Table 2: Physical Properties of Coarse Aggregate

Properties	Values
Specific gravity	2.72
Water absorption for 20 mm aggregate	1.03 %
Water absorption for 12.5 mm aggregate	1.94 %

Table 3: Physical Properties of Bottom Ash

Sl. No.	Properties	Value
1	Specific gravity	2.2
2	Water absorption	17 %.
3	Fineness modulus	2.85

Table 4: Chemical Composition of Bottom Ash

SL No	Element	Mass%
1	C	15.04
2	O	60.27
3	Al	9.02
4	Si	12.62
5	K	0.64
6	Ti	0.71
7	Fe	1.69

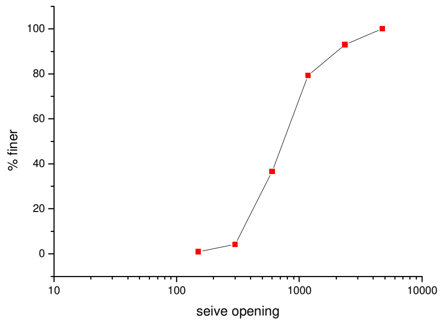

Figure 2: Particle Size Distribution Curve of Bottom Ash

Experimental Program

Ordinary Portland Cement of 53 grade conforming to relevant Indian Standard specifications [11] has been used for making the concrete mixtures. Seven mix proportions were prepared. First was control mix (without bottom ash), and the other six mixes contained bottom ash. Fine aggregate (M sand) was replaced with bottom ash by weight with a replacement range from 5% to 30% at the increment of 5%. The control mix without bottom ash was proportioned as per Indian Standard specifications [16], to obtain a 28-day cube compressive strength of 35MPa. In the first stage fresh and hardened properties of bottom ash concrete was studied and an optimum mix was found out. In the second stage, considering that optimum mix as control mix, six other mixes were prepared by adding microsilica in varying percentages (4%, 6%, 8%, 10%, 12% & 15%.) by replacing cement. For these mix proportions, quantities of materials used are shown in Table 5 and Table 6. Fresh concrete properties such as slump flow, was determined according to an Indian Standard specifications [15].

The concrete cubes of 150 mm x150mm x 150mm, cylinders of size 150 mm diameter 300 mm height and beams of size 150 mm x 150 mm x 700 mm were prepared. After required period of curing, the specimens were taken out of the curing tank and their surfaces were wiped off. The various tests performed were compressive strength test of cubes at 7th and 28th days, splitting tensile strength of cylinders at 28 days, water absorption and flexural strength of beams at 28days and modulus of elasticity as per relevant Indian Standard specifications [14].

Table 5: Trial Mix Details of Mix 1

Mixture	W/C Ratio	Cement (kg/m^3)	Sand (kg/m^3)	Bottom Ash (kg/m^3)	Coarse Aggregate (kg/m^3)	Water (kg/m^3)
Control mix	0.4	345	629.85	0	1222.65	138
BAC 5	0.4	345	598.35	31.5	1222.65	138
BAC 10	0.4	345	566.85	63.00	1222.65	138
BAC 15	0.4	345	535.35	94.50	1222.65	138
BAC 20	0.4	345	503.35	126.00	1222.65	138
BAC 25	0.4	345	472.35	157.50	1222.65	138
BAC 30	0.4	345	440.85	189.00	1222.65	138

Table 6: Trial Mix Details of Mix II

Mixture	W/C Ratio	Cement (kg/m^3)	Microsilica (kg/m^3)	Sand (kg/m^3)	Bottom Ash (kg/m^3)	Coarse Aggregate (kg/m^3)	Water (kg/m^3)
Control Mix	0.4	345.00	0	566.85	63	1222.65	138
BM 4	0.4	331.20	13.80	566.85	63	1222.65	138
BM 6	0.4	324.30	20.70	566.85	63	1222.65	138
BM 8	0.4	317.40	27.60	566.85	63	1222.65	138
BM 10	0.4	310.50	34.50	566.85	63	1222.65	138
BM 12	0.4	293.30	41.40	566.85	63	1222.65	138
BM 15	0.4	276.00	51.80	566.85	63	1222.65	138

RESULTS AND DISCUSSIONS

Properties of Fresh Concrete

Slump Test

The workability of concrete is measured by performing slump test. The test results are presented in Figures 3 and 4.

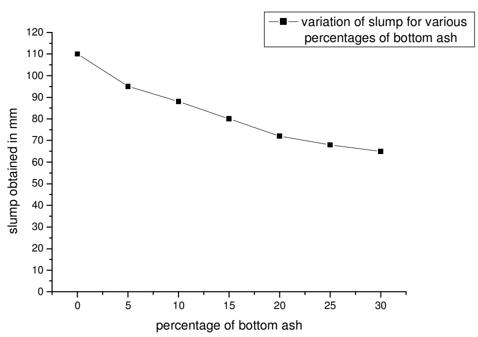

Figure 3: Slump Obtained for Bottom Ash Concrete

The test results show that slump values of bottom ash concrete mixtures decreased with the increase in level of fine aggregate replacement by bottom ash. The similar trend was observed in bottom ash concrete with microsilica.

The water absorption of bottom ash is higher than that of sand particles. The rough texture and complicated shape of particles of bottom ash also played significant role in increasing the inter particle friction. The above factors contributed towards lowering the slump. When micro silica was added to bottom ash concrete workability again decreases. This reduction is due to the higher percentage of finer particles than 150 microns.

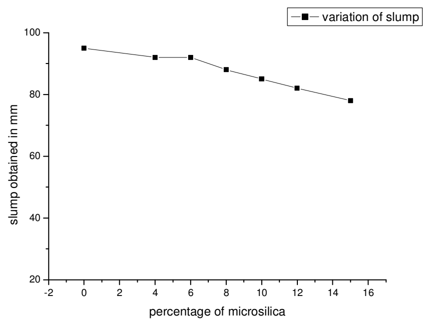

Figure 4: Slump Obtained for Bottom Ash Concrete with Microsilica

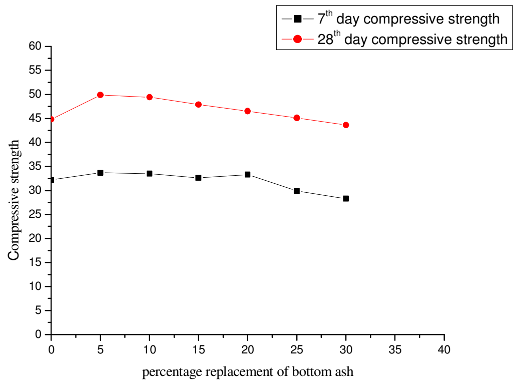

Figure 5: Variation of Compressive Strength of Bottom Ash Concrete on 7 and 28 Day Curing

PROPERTIES OF HARDENED CONCRETE

Compressive Strength Test

The 7th and 28th day cube compressive strength of bottom ash concrete are shown in Figure 5. The results of 28th day cube compressive strength of bottom ash concrete with microsilica was shown in Figure 6.

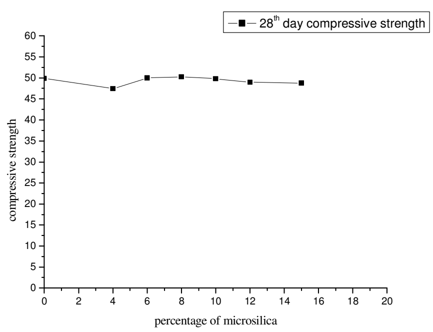

Figure 6: Effect of Microsilica in Optimum Bottom Ash Concrete

The results show that the strength development patterns of bottom ash concrete at all the levels of fine aggregate replacement with bottom ash is similar to that of control concrete. At the curing age of 7 days, concrete mixtures containing 5%, 10%, 15% and 20% bottom ash as fine aggregate gained 67.46%, 67.73%. 68.17% and 71.6% of their 28 days compressive strength respectively as compared to 72% of 28 days compressive strength gained by control concrete mixtures. At curing age of 28 days, the compressive strength of concrete mixtures containing bottom ash as partial replacement of fine aggregate surpassed that of control concrete. The factors responsible for the decrease in compressive strength of bottom ash concrete mixtures at early curing age of 7 days can be due to the replacement of the stronger material with the weaker material and absence of pozzolanic activity by the bottom ash.

The previous studies show that pozzolanic activity of coal bottom ash is slow until 14 days of curing age and after this period, the coal bottom ash particles start reacting with calcium hydroxide and forming C–S–H gel and needles [8]. It can be seen that 28^{th} day compressive strength of bottom ash concrete was increased with addition of microsilica. The results show that microsilica beyond 8 percentages has no influence on the strength gain in the mixes. In the present investigation the maximum increase in strength obtained at 8% of microsilica. Also with increase in percentage of microsilica content, the strength gain seems decreased. The main effect on the strength of microsilica is due to its reaction with lime in concrete and resulting better pore distribution in its matrix. That is there is a need for an amount of microsilica to complete these actions. Any extra quantity of microsilica merely will be dust filler in concrete. That is the reason why no significant strength gain in concrete observed when percentage of microsilica is more than 8%.

Splitting Tensile Strength Test

The splitting tensile strength results of bottom ash concrete mixtures are shown in Figure 7. The results of bottom ash concrete with microsilica are shown in Figure 8.

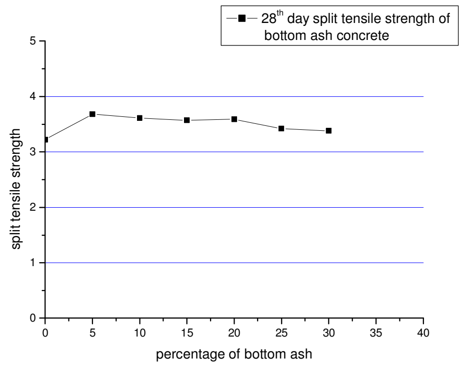

Figure 7: Effect of Bottom Ash in Split Tensile Strength of Concrete

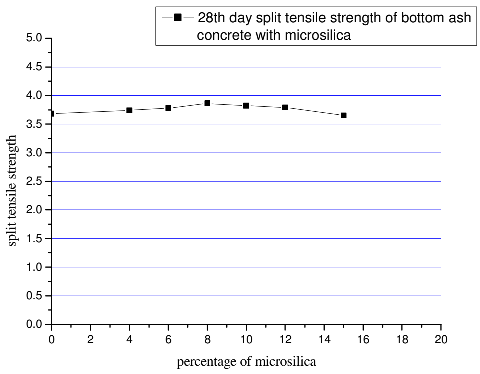

Figure 8: Effect of Microsilica in Split Tensile Strength of Bottom Ash Concrete

The test results indicate that inclusion of bottom ash in concrete improved the splitting tensile strength of concrete. The splitting tensile strength of concrete is more dependent on the quality of the paste than compressive strength. The properties of fine aggregate also affect quality of paste and interfacial transition zone in the concrete, which affect the ratio of tensile strength and compressive strength. The pozzolanic properties of bottom ash improves the quality of the paste thereby result in increase in splitting strength of concrete. The splitting tensile strength results of this investigation are in good agreement with those reported by Malkit Singh et al. [1]. At curing age of 28 days, the splitting tensile strength of bottom ash concrete mixtures incorporating 5%, 10%, 15%, 20% and 25% bottom ash as fine aggregate was 14.28%, 12.11%, 10.8%, 11.48% and 6.21% higher than that of control concrete mixture respectively. The incorporation of bottom ash in concrete shows significant increase in splitting tensile strength.

Flexural Strength Test Results

In this test, plain concrete beam was subjected to flexure using symmetrical two point loading until failure occurs. The theoretical maximum tensile stress reached in the bottom fiber of the test beam is called modulus of rupture. The results of flexural strength test were tabulated in Table 7.

Table 7: Results of Modulus of Rupture

Sl. No	Mix Designation	Ultimate Load in Tones	Modulus of Rupture in N/mm^2	Modulus of Rupture in N/mm^2
1	BAC 0	3.0	5.20	5.28
		2.8	4.97	
		3.2	5.68	
2	BAC 5	2.8	4.97	5.21
		2.9	5.15	
		3.1	5.51	
3	BM 8	2.5	4.44	4.32
		2.7	4.8	
		2.1	3.73	

Even though the compressive strength was increased, the flexural strength of concrete almost decreased when fine aggregate was replaced by bottom ash. The cracks caused by flexural load easily propagated through bottom ash particles while the normal aggregates were hard to penetrate, and consequently the direction of the crack propagation was changed by the existence of normal aggregates. Therefore, the flexural strength of concrete was decreased when bottom ash aggregates were applied. However, advanced studies have to be carried out to investigate the mechanisms of crack nucleation and propagation during compressive and flexural loading for concrete incorporating bottom ash.

Water Absorption

Water absorption of concrete specimens was determined as per the procedure given in relevant ASTM specification [18]. The concrete cubes of 7 days curing age free from visible cracks, fissures etc. were used in this investigation for determining the water absorption. The results of water absorption are illustrated in Tables 8 and 9.

Table 8: Water Absorption of Bottom Ash Concrete

Mix Designation	Water Absorption (%) at 28day Curing Age
BAC 0	5.90

Table 8:Contd.,	
BAC 5	5.82
BAC 10	6.15
BAC 15	6.49
BAC 20	6.90
BAC 25	7.06
BAC 30	7.21

Table 9: Water Absorption of Bottom Ash with Microsilica Concrete

Concrete Mixture	Water Absorption (%) at 28th day Curing Age
BM 0	5.82
BM 4	5.70
BM 6	5.81
BM 8	5.75
BM10	6.18
BM 12	6.32
BM 15	6.51

The test results show that water absorption of concrete increased with the increase in levels of fine aggregate replacement by coal bottom ash in concrete. The results proved the correlation between the permeable pore space and water absorption. With the addition of bottom ash in concrete, the connectivity between the capillaries in the paste improved. When microsilica was added to the mixture the water absorption was slightly reduced. This may due to the finer particles of microsilica. Beyond 8% replacement there was not much reduction in water absorption.

Results of Modulus of Elasticity

Modulus of elasticity of concrete mixtures was measured at the curing age of 28 days. The test results are shown in Tables 10 and 11.

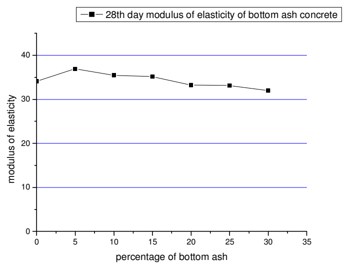

Figure 9: Effect of Bottom Ash on Modulus of Elasticity of Concrete

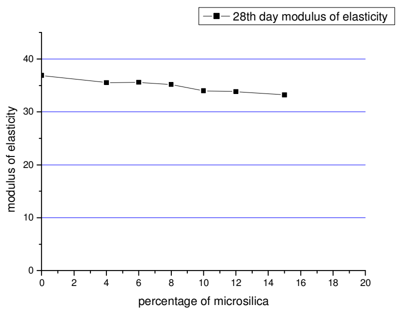

Figure 10: Effect of Microsilica in Optimum Bottom Ash Concrete on Modulus of Elasticity

Even though the compressive strength was not strongly affected, the modulus of elasticity of concrete decreased approximately linearly with the increase in replacement levels of fine aggregate with the bottom ash. The modulus of elasticity of bottom ash concrete mixtures was lower than that of control concrete mixture at the curing age of 28th day. Hence, as far as strength properties and modulus of elasticity are concerned, the concrete produced using bottom ash is suitable for structural purposes. When microsilica was added to the bottom ash concrete, it can be seen that there is decrease in the modulus of elasticity. From these results it is evident that bottom ash strongly affects the elastic behavior of concrete.

CONCLUSIONS

The present investigation was carried out to evaluate the suitability of utilizing bottom ash as a partial replacement of fine aggregates in M35 grade concrete. The study also investigated the effect of microsilica in optimum bottom ash concrete mix. Test results indicate that bottom ash from Hindustan Newsprint Limited is a suitable material to be used as fine aggregate in partial replacement of fine aggregate along with microsilica in production of structural concrete. Based on the analysis of test results and discussions following conclusions can be drawn.

- The workability of bottom ash concrete decreased on use of coal bottom ash in partial replacement of fine aggregate in concrete.
- When micro silica was added to bottom ash concrete workability again decreases.
- Compressive strength reduced marginally on the inclusion of bottom ash in concrete.
- No significant strength gain in concrete observed when percentage of microsilica is more than 8%.
- Splitting tensile strength of concrete improved on use of coal bottom ash as fine aggregate in partial replacement of sand and also when micro silica was added to the optimum mix.
- The flexural strength of concrete almost linearly decreased as the replacement level of bottom ash was increased.
- Water absorption of bottom ash concrete at 28 days curing age also increased approximately linearly with the increase in replacement levels of fine aggregate with bottom ash in concrete.
- When microsilica was added to the mixture the water absorption was slightly reduced.
- The modulus of elasticity of concrete decreased approximately linearly with the increase in replacement levels of fine aggregate with the bottom ash.

REFERENCES

1. Malkit Singh et al. "*Strength properties and micro-structural properties of concrete containing coal bottom ash as partial replacement of fine aggregate",* Construction and Building Materials 50; 246–256.
2. Bumjoo Kim et al. *"Geotechnical Properties of Fly and Bottom Ash Mixtures for Use in Highway Embankments"* Journal of Geotechnical and Geoenvironmental Engineering © asce/july 2005.
3. P. Aggarwal, Y. Aggarwal, S. M. "*Effect of bottom ash as replacement of fine aggregates in concrete*" Asian Journal of Civil Engineering (building and housing) vol. 8, no. 1 (2007).

4. Abdulhameed et al. "*Properties of concrete using tanjung bin power plant coal bottom ash and fly ash",* International Journal of Sustainable Construction Engineering & Technology (ISSN: 2180-3242) Vol 3, Issue 2, 2012.

5. M. P. Kadam et al. "*Effect of coal bottom ash as sand replacement on the properties of concrete with different w/c ratio*" International Journal of Advanced Technology in Civil Engineering, ISSN: 2231–5721, Volume-2, Issue-1, 2013.

6. P. Tang et al. "*The application of MSWI bottom ash fines in high performance concrete",* 1st International Conference on the Chemistry of Construction Materials (2012).

7. Yogesh Aggarwal, Rafat Siddique, "*Microstructure and properties of concrete u sing bottom ash and waste foundry sand as partial replacement of fine aggregates*", Construction and Building Materials 54 (2014) 210–223.

8. C. Mathiraja, "*A Study on Concrete Using Bottom Ash, Manufacturing Sand and Hybrid Steel and Coir Fibres",* IOSR Journal of Mechanical and Civil Engineering (IOSR-JMCE) Volume 10, Issue 1 (Nov. - Dec. 2013), PP 55-57.

9. Kim H K, Lee H K, "*Use of power plant bottom ash as fine and coarse aggregate in high-strength concrete",* Constr Build Mater 2011; 25:1115–22.

10. IS 12269-1987 "*Indian Standard specification for 53grade ordinary Portland cement" Bureau of Indian Standards,* New Delhi, 1997.

11. IS 2386-1963 (part 3), *"Methods of test for aggregates for concrete", Bureau of Indian Standards,* New Delhi, 1997.

12. IS 383-1970 "*Specification for coarse and fine aggregates from natural sources for concrete", Bureau of Indian Standards,* New Delhi, 1997.

13. IS 516-1959," *Indian Standard methods of tests for strength of concrete", Bureau of Indian Standards,* New Delhi, 1997.

14. IS 1199-1959, "*Methods of sampling and analysis of concrete", Bureau of Indian Standards,* New Delhi, 1997.

15. IS 10262-2009, **"***Indian Standard recommended guidelines for concrete mix design", Bureau of Indian Standards,* New Delhi, 1997.

16. IS 10086-1982 "*Specification for moulds for use in tests of cement and concrete", Bureau of Indian Standards,* New Delhi, 1997.

17. ASTM C642-97. "*Standard test methods for density, absorption and voids in hardened concrete*". West Conshohocken, USA: ASTM International; 1997.

18. BIS: 8112-1989. "*Indian standard 53 grade ordinary Portland cement – specification",* New Delhi, India: Bureau of Indian Standards; 1989.

19. BIS: 5816-1999."*Indian standard splitting tensile strength of concrete-test method",* New Delhi, India: Bureau of Indian Standards; 1999.