Experimental Study on Partial Replacement of Fine Aggregate (Sand) by Bottom Ash in Recycled Aggregate Concrete for Sustainable Construction and Structural Durability Improvement

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ABSTRACT

This paper presents the experimental investigations carried out to study the effect of use of bottom ash (the coarser material which falls into furnace bottom in modern large thermal power plants and constitute about 20% of total ash content of the coal fed in the boilers) as a partial replacement of sand in recycled aggregate concrete. The mix design was made for M35 Grade concrete. The replacement of sand with bottom ash was varied as 0%, 10%, 20%, 30%, 40% and 50%. Recycled aggregates are used instead of natural aggregates. The properties studied are compressive strength, split tensile strength and flexural strength of concrete. The strength development for various percentages (0-50%) can be easily equated to the strength development of normal recycled aggregate concrete. It was observed that the strength of concrete was decreased with increase in percentage of replacement of fine aggregate (sand) with bottom ash. The main aim is to increase the use of supplementary materials in place of both fine and coarse aggregates in the preparation of concrete.

Keywords: *Bottom ash, fine aggregate, partial replacement, recycled aggregates and recycled aggregate concrete, compressive strength, split tensile strength, flexural strength, supplementary materials.*

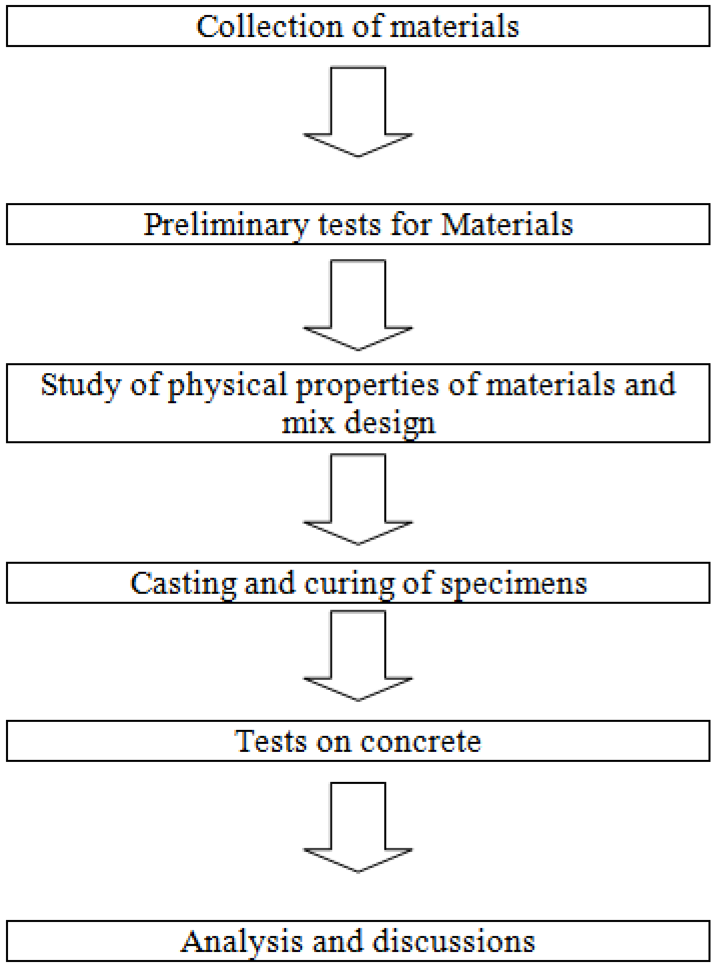
I. INTRODUCTION

Concrete is the most widely used construction material. The word concrete comes from the Latin word "*concretus*" meaning "grow together". Concrete is a mixture of cement, fine and coarse aggregates and water mainly where as in recycled aggregate concrete the natural aggregates are replaced by recycled aggregates. Due to rapid increase in demand for concrete there is scarcity of materials which leads to the use of supplementary materials for fine and coarse aggregates and cement. One such material is bottom ash which can be used to replace fine aggregate partially.

Coal based thermal power plants all over the world face serious problems in the handling and disposal of ash produced. The utilization of fly ash is about 30% in various engineering requirements that is for low technical applications such as in construction of fills and embankments, backfills, pavement base and sub base course. Coal bottom 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 is similar to that of river sand. Bottom ash based artificial lightweight aggregate offer potential for large-scale utilization in the construction work. The other advantage of using bottom ash is that it can be dust free, the sizes of bottom ash can be controlled easily so that it meets the required grading.

Many people have been carrying out on investigations on partial replacement of fine aggregate-river sand with bottom ash. Investigations are carried about variation of strength with age in bottom ash concrete compared that in normal concrete. Studies are also carried out by varying water cement ratio. The water cement ratio is slightly high in bottom ash concrete than in conventional concrete as bottom ash absorbs more water compared to river sand. In the current investigation the variation of strength of bottom ash varied recycled aggregate concrete is studied in detail and the results are found out and conclusions are made based on the results.

Methodology



II. CHARACTERISTICS OF MATERIALS USED

Cement:

Cement may be prescribed as a material with adhesive and cohesive properties which make it capable of bonding material fragments into a compact whole. The most commonly used cement in construction today is Portland cement and hence Ordinary Portland Cement of 53 grades has been selected for the investigation. It is dry, powdery and free of lumps.

TABLE 1 Physical properties of Ordinary Portland Cement

TEST	RESULT
Standard consistency	33%
Specific gravity	3.11
Fineness	7
Initial setting time	105
Final setting time	600

Recycled coarse aggregate:

Crushed aggregates of sizeless than 22mm produced from used concrete by crushing it at a local crushing plant were used. The individual aggregates were mixed to induce the required combine grading for 20mm nominal size graded aggregate confirming to IS 383-1970.

TABLE 2 Physical properties of recycled coarse aggregate

TEST	RESULT
Specific gravity	2.722
Bulk density (kg/m^3)	1418.67
Fineness Modulus	7.51

Natural Coarse Aggregate :
Crushed aggregates of size less than 22mm produced at a local crushing plant were used. The individual aggregates were mixed to induce the required combine grading for 20mm nominal size graded aggregate confirming to IS 383-1970.

TABLE 3 Physical properties of natural coarse aggregate

TEST	RESULT
Specific gravity	2.719
Bulk density (kg/m^3)	1482.67
Fineness Modulus	7.71

Fine aggregate (sand):
Those particles passing the 9.5 mm (3/8 in.) sieve, almost entirely passing the 4.75 mm (No. 4) sieve, and predominantly retained on the 75 µm (No. 200) sieve are called fine aggregate. For increased workability and for economy as reflected by use of less cement, the fine aggregate should have a rounded shape. The purpose of the fine aggregate is to fill the voids in the coarse aggregate and to act as a workability agent.

TABLE 4 Physical properties of fine aggregate-sand

TEST	RESULT
Specific gravity	2.389
Fineness modulus	2.62
Bulk Density(kg/m^3)	1345
Grading Zone	Zone II

Bottom ash:
Bottom ash was brought from the Singareni Thermal Power Plant, located atJaipur, Pegadapalli of Telangana state. Bottom ash is a by product of coal burnt in thermal power plants which is a coarse, angular material of porous surface texture predominantly sand-sized. It is composed of silica, magnesium and sulphate. Grain size typically ranges from sand to gravel. Bottom ash particles are much coarser than fly ash. Chemical composition of bottom ash is similar to the fly ash but typically contain greater quantity of carbon. Bottom ash exhibits high shear strength and low compressibility. These engineering properties make bottom ash an ideal material in design construction of dam and for other civil engineering applications. Bottom ash also exhibits a relatively high permeability and grain size distribution that allows the design engineer to use it in direct contact with impervious material. Bottom ash has proved to be an economical material because it has demonstrated to have not only good engineering property but also to have constructability benefits. Bottom ash can be used as concrete aggregate or for several other civil engineering applications where sand, gravel and crushed stone are used.

Fig.1: bottom ash

TABLE 5 Physical properties of bottom ash

TEST	RESULT
Specific gravity	2.389
Fineness modulus	2.51
Bulk Density(kg/m^3)	1495

Water:
Water is an important ingredient of concrete as it actually participates in the chemical reaction with cement. Since it gives the strength to cement concrete, the quantity and quality of water are required to be looked into very carefully. Potable tap water free from any injurious amounts of oils, acids, alkalis, sugar, salts and organic materials available in the laboratory with pH value of 7.0 ± 1 and confirming to the requirements of IS: 456 -2000 was used for mixing concrete and curing the specimens as well.

III. MIX DESIGN AND MIX DESIGNATION

Mix Design
Mix design is a process of finding the proportions of concrete mix in terms of ratios of cement, fine aggregate, coarse aggregate. The grade designation gives the characteristic strength requirement of concrete. The mix design is done as per IS: 456-2000 and IS: 10262-2009.

TABLE 6Mix proportions

Material	Cement	Fine aggregate	Coarse Aggregate	Water (lit)
Quantity (kg/m^3)	333.33	666.66	1233.33	166.67
Proportion	1	2	3.7	0.5

Mix Designation
In the present work total 7 different categories of mixes are casted by varying the amount of bottom ash as a partial replacement of fine aggregate (sand) from 0% to 50% with an increment of 10%. These mixes are clearly demonstrated in the following table.

TABLE 7 Mix designation

Mixture no	M1	M2	M3	M4	M5	M6	M7

Cement (kg/m^3)	333.33	333.33	333.33	333.33	333.33	333.33	333.33
Recycled coarse aggregate (%)	0	100	100	100	100	100	100
Natural coarse aggregate (%)	100	0	0	0	0	0	0
Fine aggregate -sand (%)	100	100	90	80	70	60	50
Bottom ash (%)	0	0	10	20	30	40	50

IV. RESULTS AND DISCUSSIONS

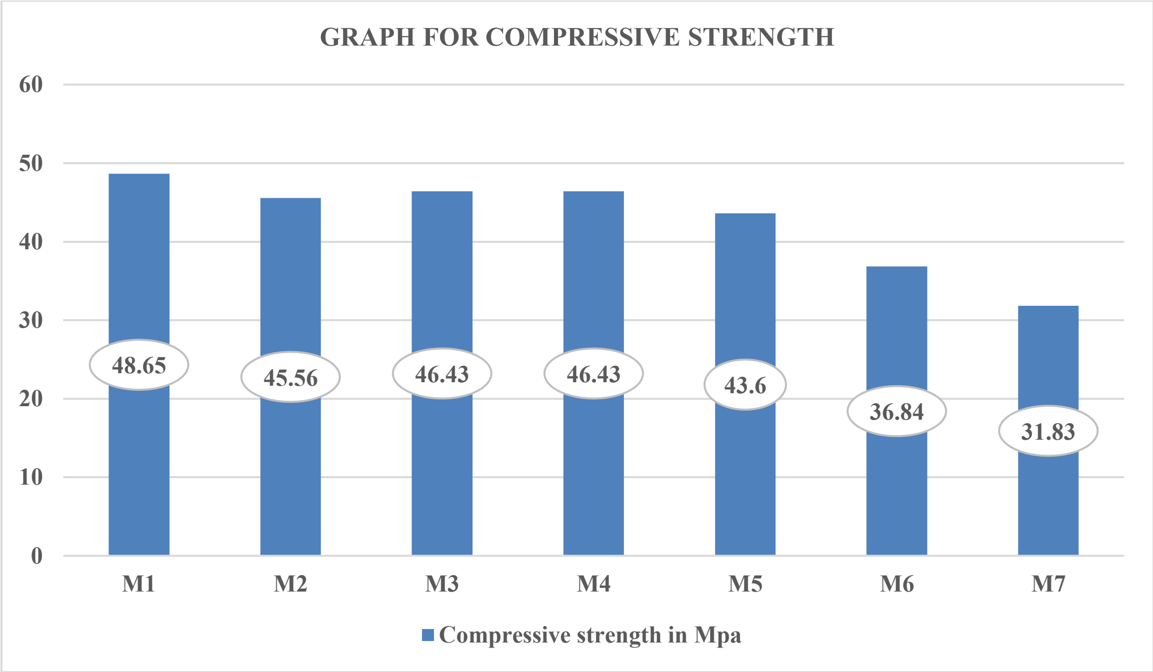
i. Compressive strength

Compressive strength test is the most common test conducted on concrete, because the desirable characteristic properties of concrete are quantitatively related to its compressive strength. Compressive strength was determined by using Compression Testing Machine (CTM) of 200 tons capacity. The compressive strength of concrete was tested using 150 mm x 150 mm x 150 mm cube specimens. The test was carried out by placing a specimen between the loading surfaces of a CTM and the load was applied until the specimen fails. Two test specimens were cast for each proportion and used to measure the compressive strength for each test conditions and average value was considered. The average values of compressive strength of 2 specimens for each category at the age of 28 days curing are shown below

Fig. 2: Compressive strength testing set up

TABLE 8 Test Results of Cubes For Compressive Strength Test

Specimen designation	M1	M2	M3	M4	M5	M6	M7
Compressive strength (Mpa)	48.65	45.56	46.43	46.43	43.60	36.84	31.83



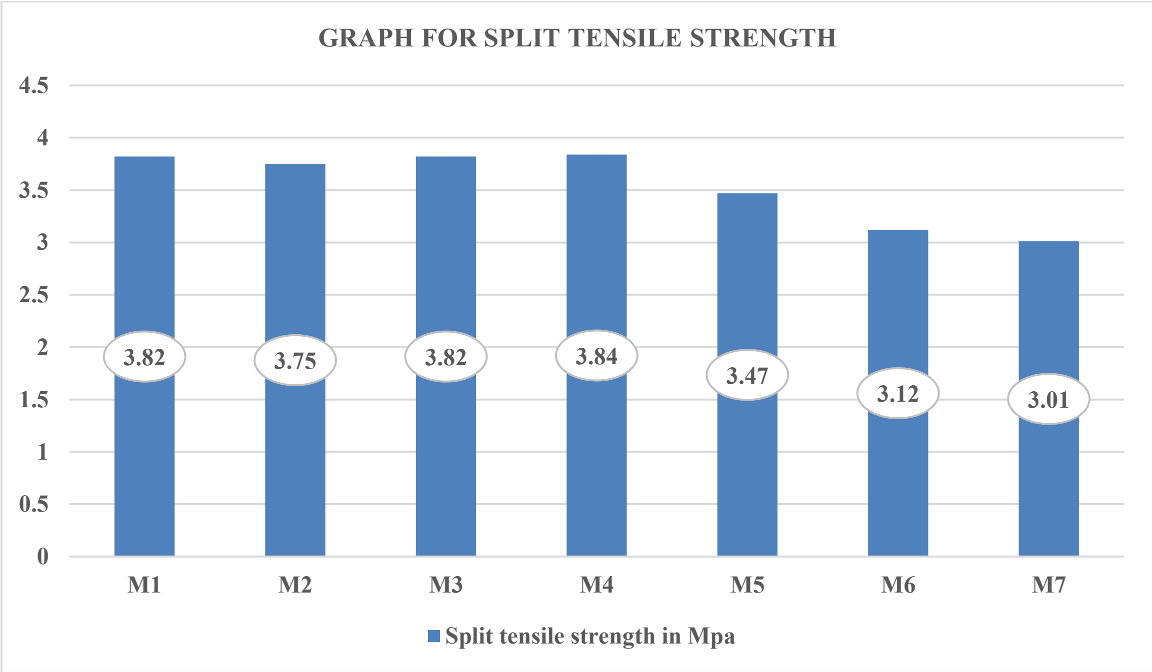
ii. *Tensile Strength*

Knowledge of tensile strength of concrete is of great importance. Tensile strength was determined using Universal Testing Machine (UTM). The split tensile strength of concrete was tested using 150 mm x 300 mm cylinder specimens and is carried out by placing a specimen between the loading surfaces of a UTM and the load was applied until the specimen fails. Two test specimens were cast for each proportion and used to measure the tensile strength for each test conditions and average value was considered. The average values of 2 specimens for each category at the ages of 28 days curing are shown below

TABLE 9 Test Results Of Cylinders for Split Tensile Strength Test at 28 Days

Specimen designation	M1	M2	M3	M4	M5	M6	M7
Split tensile strength (Mpa)	3.82	3.75	3.82	3.84	3.47	3.12	3.01

Fig 3: Tensile strength setting setup



iii. Flexural Strength

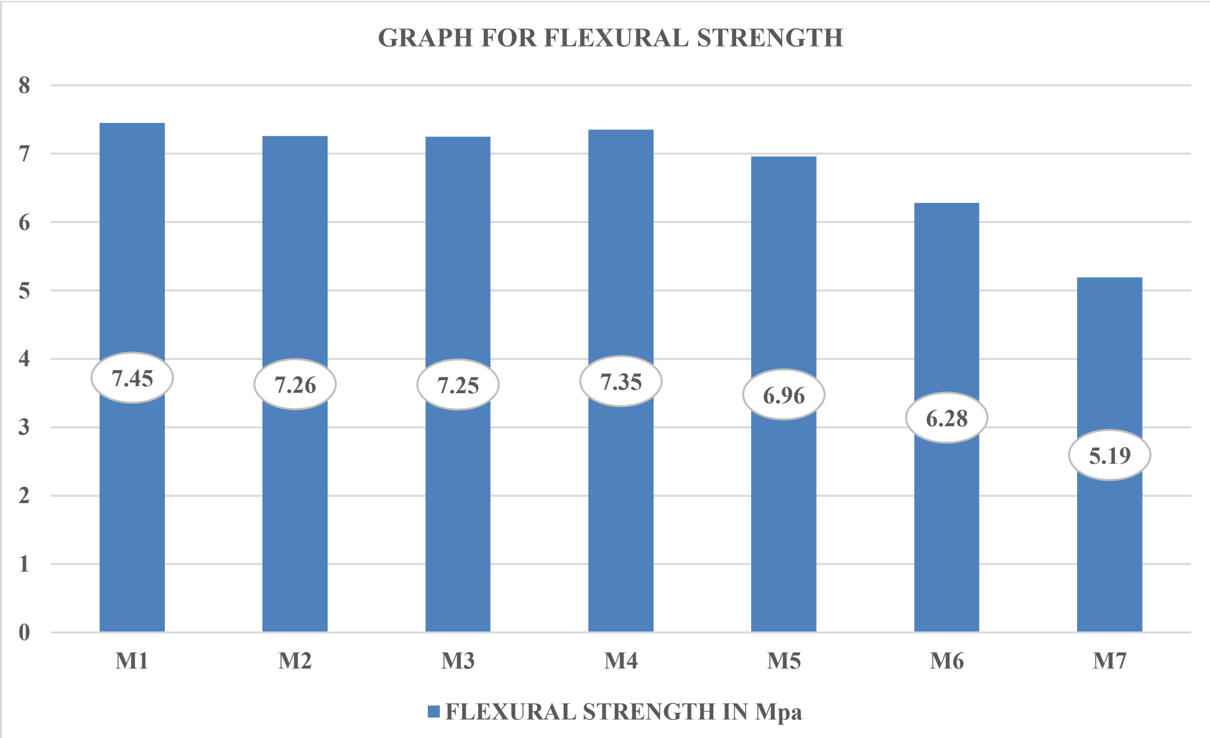
Flexural strength is a measurement that indicates the resistance of a material to deformation when placed under a load. The values needed to calculate flexural strength are measured by experimentation, with rectangular samples of the material placed under load in a 2 point loading testing setup. The strength of a material in bending, expressed as the stress on the outermost fibers of a bent test specimen, at the instant of failure is called flexural strength. Prism specimens were tested for flexural strength. The tests were carried out confirming to IS: 516-1959 (8). The specimens are tested under two-point loading. The average values of 2 specimens for each category at the age of 28 days are shown below

Fig. 4: Flexural strength testing set up

TABLE 10 Test Results of Prisms for Flexural Strength at 28 Days Curing

Specimen designation	M1	M2	M3	M4	M5	M6	M7

Flexural strength (Mpa)	7.45	7.26	7.25	7.35	6.96	6.28	5.19



V. CONCLUSIONS

1. The test results shows that the bottom can be used as a replacement material for river sand in the recycled aggregate concrete.
2. The recycled aggregate concrete with 10%, 20% and 30% replacement satisfies the target mean compressive strength of M35 grade which is about 43Mpa, however higher the percentage addition of bottom ash reduces the strength of recycled aggregate concrete. The maximum strength is for 20% replacement which is 46.43.
3. The tensile strength of 10% and 20% replacements at 28 days shows the consistency in attaining the required satisfactory results.
4. The flexural strength of 10%, 20%, 30%, 40% and 50% are meeting the required value which is around 4.14Mpa.
5. Hence bottom ash can be used to replace river sand as fine aggregate in recycled aggregate concrete. As 20% is yielding higher values for all the three tests, it can be considered as optimum.

REFERENCES

1. *P.Aggarwal, Y.Aggarwal and S.M. Guptha, Effect of Bottom ash as Replacement of fine aggregate in Concrete, Asian journal of Civil Engineering (building and Housing), vol.8, No.1,2007.*
2. *M.Veera Reddy, Investigations on Stone Dust and Ceramic Scrap as coarse Aggregate*
3. *Dilip Kumar, Ashish Gupta and Sri Ram, Uses of Bottom Ash in the Replacement of fine aggregate for making concrete, Vol.4, No.6, Dec 2014.*
4. *Dr. R.G.D' Souza, Replacement of Fine Aggregate with Bottom Ash in Concrete and Investigation on Compressive Strength.*

5. *Kiran Kumar M S, Harish K S, Vinay R B and Ramesh M, Experimental Study on Partial Replacement of Fine Aggregate by Bottom Ash in Cement Concrete, International Research Journal of Engineering and Technology, Vol.05, Issue 05, May-2018.*
6. *IS:383-1970, Specification for Course and fine aggregate from natural sources for concrete, Bureau of Indian standard, New Delhi.*
7. *IS:10262-2009, Guidelines for concrete mix design proportioning, Bureau of Indian standard, New Delhi*
8. *IS:516-1959, Methods of Tests for Strength of Concrete, Bureau of Indian standard, New Delhi.*
9. *IS:9103-1999, Concrete Admixtures-specification, Bureau of Indian standard, New Delhi.*