THE EFFECT OF ALUMINIUM DROSS AND BOTTOM ASH ON MECHANICAL PROPERTIES OF CEMENT CONCRETE

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ABSTRACT
Being a part of experimental investigation to mitigate the problems posed by various waste products from metal and power plant industries w.r.t. global perspective being used as landfill or recycling, but the re-usage reduces environmental contamination to a substantial extent and exploitation of natural resources with overall economic benefit. The present study on M25 grade of concrete consisting aluminum dross and bottom ash coming from various industries across the globe used to focus on mechanical properties through compressive and flexural strength tests where the cement replaced partially by aluminium dross up 20% on various proportions and fine aggregates at 15% by bottom ash on a constant scale.

Keywords: Aluminium dross (AD), Bottom ash (BA), M25 grade of concrete, Compressive strength, and Flexural strength.

I. Introduction
M25 grade of concrete is designed in accordance with the latest IS codes and properties of all the ingredients like aluminium dross, bottom ash, cement, coarse aggregate, fine aggregate, and water. The aluminum dross (AD) utilized in this investigation was procured from 'VAKKAL IMPEX Private Limited', an aluminum extrusion firm located in Hindupur, Anantapur, Andhra Pradesh. The waste is irregularly shaped, black in appearance, and contains small lumps and particles of aluminum produced by burning aluminum scraps (raw material) in a furnace at a temperature of about 1900°C. The total amount of waste generated each day is eighteen tons. Before using the waste to make concrete, it was crushed, ground, and sieved using a ninety µm sieve size. The aluminium dross obtained from smelters replaced to cement in concrete production at different scales from 0 to 20% at every 5% increment levels. Bottom ash (BA), a by-product of coal-fired thermal power plants obtained from Rayalaseema Thermal Power Plant, Kadapa, Andhra Pradesh, is currently considered as a sand replacement at i.e., 15%, being stable right through the study. Measuring the particle size distribution of bottom ash shows that 100% of particles are smaller than 56 µm and 29% were smaller than 31.30 µm with the average diameter of the particle size distribution being 33.2 µm with an average standard mean deviation of 8.25 µm for bottom ash.

II. Materials and methods
The Ordinary Portland Cement (53 MPa) with a consistency of 27%, relative density of 3.16, and fineness of 95%, 45 minutes of initial setting time and 383 minutes of final setting times, which conforms and tested as per various Indian Standard specifications /codes [36] used. Locally available natural sand free from clay matter, silt and organic matter having a maximum size of 4.75 mm used as fine aggregate, confirms to grading zone II, as per IS 383:2016 [36], table 4 under clause 4.3. Crushed stone of maximum size 20 mm used as coarse aggregate, confirms to IS 2386:2022 [36]. The properties of coal bottom ash are according to IS 3812:2003 [36]. The sieved aluminium dross allowed to soak in water to remove the hazardous gases, stirred continuously at constant intervals

until the added water evaporates. The entire process of soaking in water and allowing to dry in open air takes typically 4-5 days.

III. Experimental programme

Concrete mix proportions assigned names as AD5BA15, AD10BA15, AD15BA15 and AD20BA15 (AD5BA15 means aluminium dross replaced to cement at 5% weight to weight ratio and bottom ash replaced to fine aggregates i.e., to natural sand at 15% weight to weight ratio) are prepared including the control mix (CM) as per IS 456:2000 [36] and IS 10262:2019 [36], to obtain the target compressive strength for 28 days of curing in water of 31.6 N/mm^2. As per Table No. 41 of SP 23:1982 [36], maximum size of nominal aggregate as 20 mm ranging from 4.75 mm to 20 mm are taken to design the mix. The water to cement ratio remained constant throughout the study at 0.50. Moderate slump allowed while designing the mix and exposure to atmospheric considered as severe. The fine aggregates, coarse aggregates, sieved aluminium dross, bottom ash, and cement to an accuracy of 0.10 percent of the total weight of the batch are taken to cast required number of concrete cubes and beams. All the ingredients were thoroughly mixed in a dry state until a homogeneous mixture was obtained. Care being taken to prevent intrusion of foreign materials like dust, clay, paper, cloth, wood, and organic matter etc. Potable running tap water available in the laboratory added in three stages to the turned up dry concrete mixture i.e., 50% to the dry concrete mixture in the first stage; 40% to the wet mixture; Staying 10% of water was sprinkled on the mixture and thoroughly mixed. Now, the preliminary and fresh concrete properties are noted down for reference and then taken into moulds of different sizes as per testing requirements. The time between final dose of water added to concrete mixture and concrete taken into moulds is ensured to fall under initial setting time of cement. The moulds shall be of 150 mm side cubical size conforming to IS 10086:2008 [36] for compressive strength test and mould of size 500 mm x 100 mm x 100 mm made of non-absorbent materials like steel or iron cast as per ASTM C293 [13]. The moulds are applied with non-absorbent oils to reduce the friction and roughness of walls interface with concrete. The specimens of standard sizes were cast at once followed by mixing, after conducting the tests on fresh concrete. To get a smooth finish and get rid of extra material, the specimens' top surface was scraped. Since expansion in the concrete cubes and beams is evident after allowing them to cure in air to develop initial hardness, proper care taken to ensure little expansion in the concrete cubes and beams. After a day in room temperature, the moulds were allowed to harden, the samples were taken out with due care and allowed to cure in potable running tap water stored in the tank until the test required them to be done. The respective proportions of ingredients including replacement materials are as follows.

Table1 Mix proportions of various ingredients in cement concrete (Kg/m^3)

MIX ID → INGREDIENTS ↓	**CM**	**AD5BA15**	**AD10BA15**	**AD15BA15**	**AD20BA15**
Cement	406.00	385.70	365.40	345.10	324.80
Aluminium dross	0.00	20.30	40.60	60.90	81.20
Fine aggregate	709.27	602.88	602.88	602.88	602.88
Bottom ash	0.00	106.39	106.39	106.39	106.39
Coarse aggregate	1132.35	1132.35	1132.35	1132.35	1132.35
Water	203.00	203.00	203.00	203.00	203.00

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IV. Mechanical properties and results

A. Compressive strength

The concrete mixed on watertight, non-absorbent platform with shovel, trowel or similar suitable arrangements taken into 150 mm x 150 mm x 150 mm cast iron moulds in three layers with proper compaction while filling and after filling to an approximate height 50 mm on each time, the moulds filled with concrete are placed over vibration table for further compaction, left for air curing for 24±1/2 hours at an ambient room temperature. Compressive strength of all the prepared specimens after sufficient curing period are taken out to remove excessive hardened loose concrete to get plane surface on all sides and wiped-off to remove excessive moisture content and the specimens kept at ambient room temperature for another one day. The bearing or flat surfaces of the compression testing machine were cleaned, and any loose materials or dust was taken off from the surfaces of the concrete specimen that were to be in contact with the compression plates. The concrete specimens are loaded into compressive strength test machine at center of the platform, ensured to have maximum surface area. The loading pattern and evaluation of compressive strength of the concrete specimens is as per IS 516:2004 [36]. The average value of the three samples rounded-off to nearest two decimals taken to report the compressive strength of the respective mix Id, the results are as follows.

Table2 Compressive strength of all mixes for different curing periods (N/mm^2)

MIX ID → CURING PERIOD ↓	CM	AD5BA15	AD10BA15	AD15BA15	AD20BA15
3 days	7.80	8.20	9.32	7.60	6.20
7 days	16.63	20.16	22.40	18.88	17.76
14 days	22.21	23.33	24.44	19.25	17.83
28 days	28.28	30.60	32.20	22.22	20.20
60 days	31.11	30.89	32.45	23.78	21.61
90 days	31.36	31.00	32.67	23.97	21.79
180 days	31.55	31.19	32.89	24.09	21.90
360 days	31.70	31.34	33.05	24.28	22.07

B. Flexural strength

The flexural strength test is an indirect strength test on unreinforced concrete beams or slabs to know the ability against bending or flexure. The indirect tensile strength can be assessed by conducting a three-point load test as per ASTM C78 [11] or center point load test as per ASTM C293 [13]. This test provides crucial data for structural design, quality assurance, and performance evaluation of structural elements like beams, slabs, bridges, and pavement constructions to assess their behavior under bending or flexural stresses.

Concrete filled into the moulds in 3 layers of the same thickness. Proper compaction through tamping bar on each layer for 35 number of blows ensured to achieve dense specimen without voids by tamping evenly over the whole beam mould and through each layer's depth. The concrete specimen placed over the testing machine having two steel rollers of 38 mm in diameter, used for support, and loading points to the specimens, separated by forty centimeters from center to center as the case based on size of specimen i.e., 100 mm depth. The length of the rollers was at least 10 mm more than the width of the test specimen, all the rollers except the rigid ensured for capability to have rotation against their own axis. The load applied through two similar rollers mounted at the third points of the supporting span that is, spaced 13.30 centimeters from center to center. The weight shared equally between two rollers, and all rollers are mounted in such a way that the weight is applied evenly without twisting or holding the concrete specimen in place. Flat parts where the rollers touch and get rid of any sand or other stuff on the specimen under testing are cleaned.

The rollers on the inner side are placed at the same distance from each other as the rollers on outside, such that the entire system is organized in a systematic way. The test specimen placed in the machine in such a way that at middle correctly with the long side in the middle. The specimen is positioned perpendicular to the rollers i.e., in a direction that is perpendicular to the direction of pushing or pulling. No packing between the bearing surfaces of the specimen and rollers allowed. For moulded specimens, the mould filling direction kept normal to the direction of loading. The application of load follows at a rate of loading at a rate of 180 kg per minute for the 10-centimeter specimens.

Flexural Strength, also known as modulus of rupture (fb) is calculated by,

$$\text{fb} = \frac{\text{pl}}{\text{b}d^2}$$

Where,
a = distance from the line of fracture to the closest support, measured in the middle of the side of the specimen that is being under tension
b = Width of specimen measured in centimeters
d = Depth at failure point in centimeters
l = Length that is supported in centimeters
p = Applied load i.e., maximum in kilograms

The flexural strength is calculated using the standard formula provided in the testing standard, typically involving the division of the maximum applied load by the cross-sectional area of the specimen and the distance between the supports. The results of the test, including the specimen dimensions, applied load, calculated flexural strength, and any observations related to the failure mode or behavior of the material, are reported in a comprehensive test report.

Table3 Flexural strength of all mixes for different curing periods (N/mm^2)

MIX ID → CURING PERIOD ↓	**CM**	**AD5BA15**	**AD10BA15**	**AD15BA15**	**AD20BA15**
28 days	4.01	4.11	4.45	4.40	4.39
60 days	4.12	4.23	4.46	4.38	4.35

V. Conclusions

i. Due to formation of voids aided by adding fine aluminum dross, the expansion in concrete cubes and beams observed which is a significant change in size noticed after casting concrete cubes and beams.
ii. As the replacement level of aluminium dross goes on increases to cement, the expansion in concrete cubes and bottom ash also increased.
iii. From the experimental consequences, optimum compressive strength noticed in

AD10BA15 mix Id, contains 10% aluminium dross replaced to cement and 15% bottom ash replaced to sand for all the curing ages i.e., from 3 days to 360 days in comparison to compressive strength values of control mix.

iv. The percentage increase in compressive strength of AD10BA15 mix w.r.t. the curing period from 3 days to 360 days follows as 19.49, 34.70, 10.04, 13.86, 4.31, 4.18, 4.25 and 4.26, noticeable significance from 3 days to 28 days but there after the increase in compressive strength observed to be stabilized at an average rate of 4.25%.

v. The specimens of size 500 mm x 100 mm x 100 mm are evaluated for flexural strength for 28 days and 60 days curing, the nature of failure observed across all the samples in flexural strength test are falling under Type-A.

vi. The flexural strength of control mix increased by 2.74% from 28 days to 60 days curing and AD10BA15 mix increased by 0.20%, however, the average percentage increase in flexural strength of optimum mix i.e., AD10BA15 w.r.t. control mix found to be 9.63%.

vii. Based on the physical, chemical, and mechanical properties of the aluminum dross and bottom ash replaced cement concrete, mix AD10BA15 found to be optimistic, conserves nature and saves the raw materials and ecology.

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