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Durability Studies on Aluminium Dross and Bottom Ash Replaced Cement Concrete

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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 re-usage reduces environmental contamination to a substantial extent and reduces exploitation of natural resources with overall economic benefit. Various durability studies on a micro-scale were done on aluminum dross and bottom ash coming from various industries across the globe to produce ceramics, mortar, cement, and concrete, however, the present study focused to bring the significance of durability aspect through 'RCPT', 'water absorption', 'acid attack', 'sulphate attack', and 'alkaline attack test' on concrete partially replaced by aluminium dross to cement on various proportions and bottom ash to fine aggregates on a constant scale.

Keywords: Aluminium dross (AD), Bottom ash (BA), Concrete, Compressive strength, Loss in weight, and Durability tests.

1. Introduction

For economic and technical reasons, numerous industrial byproducts are becoming increasingly utilized by the cement, concrete industries, and construction sector. In concrete, cement aids binding and fine aggregate being a major constituent assists to produce workability as well as homogeneous structure. As we know the air and soil pollution rate has increased to multi folds in the last few decades, but manufacturing of both cement and fine aggregates adversely affects the atmosphere as it includes processes like crushing, combustion, blasting, and grinding. Quarrying, blasting, and dressing of these materials should be avoided or decreased to the minimal extent at unnecessary places. Hence, finding an alternative material to avoid this to make eco-friendly concrete is essential. However, many materials are available in the global market and the research on different substitutive materials for fine aggregate and cement is going on in smaller scale. Based on existing literature studies and experimental investigations, aluminium dross and bottom ash are used for fine aggregate replacement i.e., cement and sand in this study. Aluminium dross is a by-product containing aluminum residue that forms during smelting, casting, and recycling of aluminum and its alloys in primary smelters, foundries, and recycling plants. The incombustible bottom ash is a by-product, gritty, granular, and collected from the bottom of furnaces. Most of the ashes produced at coal-fired power plants are waste only and will produce serious air pollution and reduction in soil fertility if dumped in ash ponds along with leaching issues, hence, the waste if used as a partial replacement, may help to reduce the adverse effects on the environment. One of the essential obstructions to the useful repurposing of industrial residues such as ‘aluminum dross’ and ‘bottom ash’ remains may be a need of technical data that researchers can employ to assess the effectiveness and cost-efficiency on incorporating these by-products in lieu of the characteristic cement and natural sand since the characteristics of these materials will change from source to source. The engineering properties and performance of cement and natural sand can be evaluated from the literature to utilize them in initial design processes [1]. Then again, mechanical by-products are rare in comparable information, and there's not sufficient proof to confirm that mechanical by-products, which take after cement and sand, moreover, have comparative designing highlights. It is imperative to allow designers this valuable information since building for maintainable improvement is getting to be increasingly imperative. Satisfying this requirement is the essential reason for this consideration. Upon considerable points, exploring the impact of the utilization of aluminum dross as a halfway substitution of cement in different rates (0-20%) and bottom ash residue remains as partial substitution for natural sand at a consistent level of 15%, on concrete durability properties is taken. ‘Concrete durability’ is characterized as its resistance and capacity of members for deleterious actions such as chemical and weathering, wear and tear, or any other form of deterioration to align with environmental changes for the designed life span [14], [19]. When subjected to adverse environmental conditions, durable concrete can keep up its unique original shape, quality, and serviceability. Concrete that has been legitimately prepared, tested, and arranged can provide service for little to no maintenance.

2. Experimental Program

The prima facia of the captioned work is to produce M25-grade concrete with locally available waste products such as aluminium dross and bottom ash. The aluminum dross (AD) utilized in this investigation was procured from VAKKAL IMPEX PVT LMT, an aluminum extrusion firm located in Hindupur, Anantapur, Andhra Pradesh. The waste is irregularly shaped, black in appearance, contains tiny particles of aluminum extracts [20]. Daily output of total waste generated is about 18 tons approximately. The aluminium dross crushed to powder form, only the powder passed though 90 μm sieve [4] will be used to replace cement to produce concrete at different scales [5] along with bottom ash [17], is currently considered as a sand replacement waste material at a constant level i.e., 15%, obtained from Rayalaseema Thermal Power Plant, Kadapa, Andhra Pradesh. Structural distribution of each element in the bottom ash is distinctive and varies; however, finer particles tend to contain higher levels of trace minerals due to the increased surface area to weight ratio [8]. Ordinary Portland Cement (53 MPa) with a consistency of 27%, relative density of 3.16, and 95% fineness, IST and FST’s of 45 minutes and 383 minutes (about 6 and half hours) was used, which meets and tested as per various IS specifications / codes [25]. Natural sand from local riverbanks free of clay, silt, and organic impurities, etc.,[20] adopted to zone 2, as per IS 383:2016 [23], [25], table 4 under clause 4.3 used as a fine aggregate along with 20 mm crushed stone as coarse aggregate confirming to IS 2386:2022 [25]. The characteristics of 'coal bottom ash' adhere to IS 3812:2003 [25]. Distribution of particle size follows as; all the bottom ash particles are falling under 56 μm out of which 29% were below 31.30 μm, with mean of 33.2 μm and SD of 8.25 μm [7].

Five mix proportions are prepared including the control mix (CM) based on 20 mm maximum size coarse aggregate and as per IS 456:2000, IS 10262:2019 and Table No. 41 of SP 23:1982 [25], to obtain the target compressive strength for 28 days of curing in water of 31.6 N/mm^2. Weighed quantities of aggregates like sieved aluminium dross, bottom ash, cement, sand and crushed stones are mixed in dry state to obtain consistent homogenized mixture. Potable running tap water available in the laboratory was then added in three stages i.e., 50% of the total amount to the dry concrete mixture in the first stage, turned up; 40% of water to the wet mixture, again turned up; the left-over percentage of water was sprinkled on the above mixture, turned up to achieve homogenized mixture. The potable running tap water stored in the tank is used for curing after preparation of concrete samples.

The moulds applied with non-absorbent oil on all the surfaces uniformly to achieve smooth surface on all sides of concrete samples [27]. The moulds of standard sizes are used to cast concrete samples followed by mixing, after conducting the tests on fresh concrete. The concrete filled into the mould in three equal layers of approximate depth of 50 mm, each layer compacted with the help of tamping rod and proper compaction ensured without segregation or laitance. Each layer shall be compacted either by hand or by vibration. The strokes of the bar shall be distributed in a uniform manner over the cross-section of the mould. The number of strokes per layer required to produce specified, conditions will vary according to the type of concrete. After the top layer has been compacted, the surface of the concrete shall be finished level with the top of the mould, using a trowel, and covered with a glass or metal plate to prevent evaporation. Now, the moulds filled with concrete are allowed to harden for one day without water in damp area and free from vibrations, and concrete samples are removed from moulds with minimal disruption to surfaces so that smooth finish without extra material by scrapping can be achieved. The temperature of the place of storage shall be within the range of 22 to 32 ^{0}C. After the period of 24 hours, they shall be marked for later identification, removed from the moulds and unless required for testing within 24 hours, stored in clean water at a temperature of 24 to 30 ^{0}C until they are transported to the testing laboratory [20]. The dimensions of the specimens to the nearest 0-2 mm and their weight shall be noted before testing. Proportions of aluminium dross, bottom ash, cement, coarse aggregates, fine aggregates and water in concrete are shown under Table 1.

Table 1: Proportions of individual ingredients in Concrete

Mix ID	Mix proportions (kg/m^3)					
	Cement	AD	Fine aggre.	BA	Coarse aggre.	Water
CM	406.00	0.00	709.27	0.00	1132.35	203.00
AD5BA15	385.70	20.30	602.88	106.39	1132.35	203.00
AD10BA15	365.40	40.60	602.88	106.39	1132.35	203.00

Mix ID	Mix proportions (kg/m^3)					
	Cement	AD	Fine aggre.	BA	Coarse aggre.	Water
AD15 BA15	345.10	60.90	602.88	106.39	1132.35	203.00
AD20 BA15	324.10	81.20	602.88	106.39	1132.35	203.00

The various durability tests performed on concrete specimens are depicted below under **Error! Reference source not found.**.

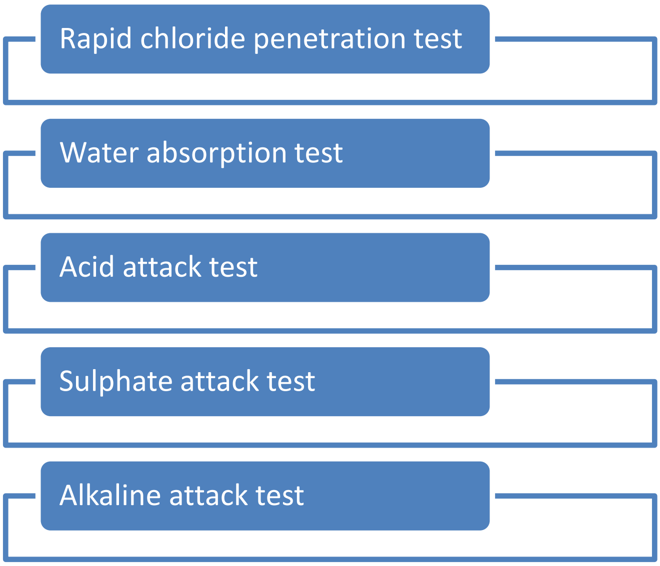

Figure 1: Schematic work flow of durability tests on concrete mixes

3. Experimental Methods and Results

The concrete moulds are used to cast concrete samples of size measuring 150 mm as sides to evaluate compressive strength and 100 mm diameter with 50 mm thickness are used to assess rapid chloride permeability [13], [15]. The concrete samples having smooth finish without extra material are allowed to cure for 28 days at ambient room temperature in curing tank. The surface of concrete samples taken out from the curing tank are wiped off for cleanliness to remove dust and others [1]. The concrete samples are used for various tests like compressive strength (cubes having 150 mm side) as per IS 516:2004 [26], and 'RCPT' as per ASTM C1202 [12] [13], 'water absorption capacity test' as per ASTM C642-97 [10], [21], 'acid attack test' as per ASTM C267-20 [9], 'sulphate attack test' as per ASTM C1012-10 [11], and 'alkali attack' as per relevant standard procedures [26].

A. RAPID CHLORIDE PENETRATION TEST

The RCPT complies with ASTM C1202 [12], [13] owing to its simplicity and speediness to assess the resistance of any concrete member against penetration of chloride ions as a durability-based quality control. A constant voltage measured in amperes is applied to a concrete specimen continuously for six hours and recorded in coulombs since coulomb is equivalent to ampere-second [2]. Consequently, the charge passing through a concrete specimen in 60 seconds would be equal to 60 coulombs, and one ampere would be one coulomb per second. Concrete is more susceptible to chloride ions if the charge passes more, indicating higher permeability and vice versa. The concrete samples saturated for 28 days in curing tank having a diameter of 100 mm with 50 mm are placed in between single cell reservoirs filled with 3% NaCl solution and 0.30 M NaOH solution. A brass mesh ended by a copper leading is used to prepare the internal groove for safer and simpler power connections. Single cell reservoirs are applied with a constant voltage of 60 V, DC power for six hours. The applied electric current passing through the concrete samples measured at constant time intervals and noted for further analysis to know the rating of the concrete samples. It is figured out by an LCD screen connected to the cells. The average current flowing through a cell can be determined using trapezoidal rule formula [3].

Table 2: Chloride permeability rating of various concrete mixes

Mix ID	Charge passed (Coulombs)	Chloride permeability rating
CM	2100	Moderate
AD5BA15	1680	Low
AD10BA15	1950	Low
AD15BA15	1770	Low
AD20BA15	1440	Low

B. WATER ABSORPTION TEST

Even though water is available from diverse sources like seawater and groundwater in nature, only potable water is used in concrete. Whenever water comes in contact with concrete, they are exposed to physical and chemical action, and this results in deterioration. The water absorption test in accordance with ASTM C642-97 [10], [21] performed on three concrete samples for each mix after curing for 28 days in water including the control mix. Concrete specimens dried for one day at 110 ^{0}C temperature by keeping them in an oven and the dry unit weight of specimens recorded as (W_1) [22]. The specimens after collecting from the oven are exposed for drying. These specimens are exposed to water and the weight of the specimens is measured at an interval of 12 hours (W_2). The water absorption of the tested specimen arrived as follows:

$$\text{Water absorption (\%)} = \frac{(W_2 - W_1)}{W_1} X100$$

The water absorption as % loss in weight has been evaluated for all the mixes including the control mix which has been used for different tests viz., acid attack, sulphate attack, and alkaline attack tests, test will be repeated to get set of successive readings are same.

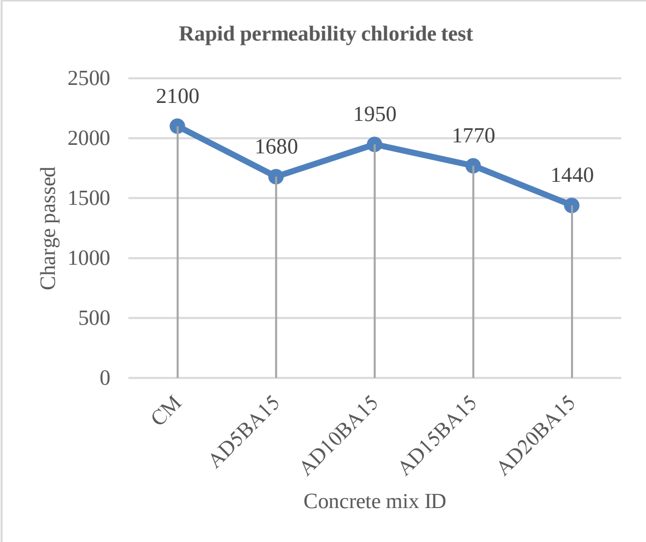

Figure 2: Variation of chloride ion permeability for various concrete mixes

C. Acid attack test

Acid attack test on concrete is not an unexpected one but leaches $Ca(OH)_2$ from the cement paste of hardened concrete and leads to reduction in cross section of concrete members after impacting the binding and strength properties adversely.

The concrete cubes having 150 mm as sides kept for 28 days in water and kept in room temperature for one day to remove the excess engrossed moisture in the samples, now the samples are kept in 10% of hydrochloric acid (HCl) for 60 days. The samples are evaluated for resistance to acid as per standards of ASTM C267-20 [9]. The pH values were maintained periodically, and samples are checked for compressive strength and forfeitures weight. Change in weight of the samples has been noticed for all the samples due to the deterioration of the outer surfaces. Additionally, the samples' compressive strength has decreased in comparison to their initial strength.

Table 3: Acid attack test on various concrete mixes

Mix ID	without acid - 28 days compressive strength (MPa)	with acid - 60 days compressive strength (MPa)	% loss in compressive strength	% loss in weight
CM	28.28	25.51	9.80	0.15
AD5BA15	30.60	26.87	12.20	0.41
AD10BA15	32.20	27.63	14.20	0.43
AD15BA15	22.22	18.62	16.20	0.45
AD20BA15	20.20	16.28	19.40	0.48

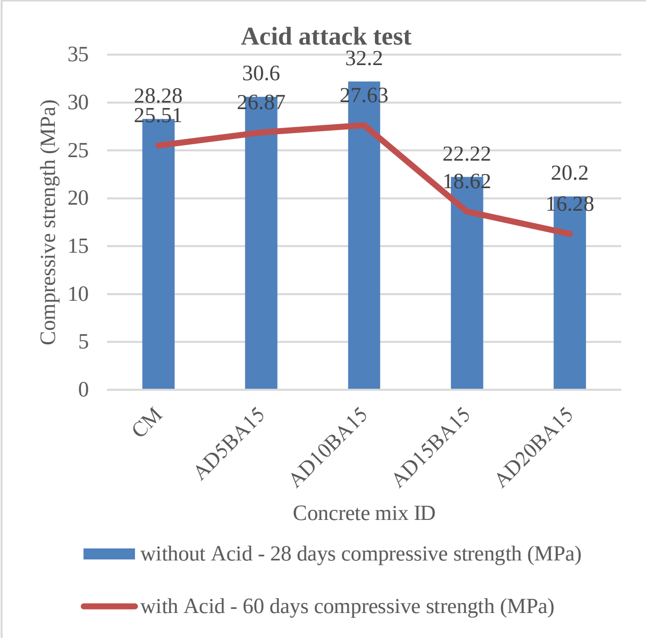

Figure 3: Variation of strength on account of Acid attack

D. Sulphate attack test

The sulphate attack resistance test has been done as per the standards of ASTM C1012-10 [11]. In a 'sulphate attack', the sulphate reacts to cause disruption of the cementitious materials in the paste, so that cohesion will lose and finally strength. The responsible components for sulphate attack on concrete specimens are water-soluble salts containing sulphate, such as alkali-earth i.e., magnesium sulphate and calcium sulphate, and alkali i.e., potassium sulphate and, sodium sulphates that can react chemically with other components of the concrete to accelerate the deterioration process of concrete [12], [18]. The concrete cubes having 150 mm as sides kept for 28 days in water and kept in room temperature for one day to remove the excess engrossed moisture in them, were taken into 5% concentrated ($MgSO_4$) solution for sixty days [6]. The concrete samples are checked for weight loss and compressive strength loss. Noticeable change in weight has been observed since the outer layer deteriorated which is due to numerous combined complex factors, and also loss in weight has been observed through the formation of gypsum on the surfaces. Additionally, decrease in compressive strength observed due to deterioration supported by spalling, mass loss, and softening on the surfaces as compared to the initial strength [4].

Table 4: Sulphate attack test on various concrete mixes

Mix ID	without sulphate attack - 28 days compressive strength (MPa)	with sulphate attack - 60 days compressive strength (MPa)	% loss in compressive strength	% loss in weight
CM	28.28	27.08	4.25	0.08
AD5BA15	30.60	28.82	5.81	0.10

AD10BA15	32.20	29.97	6.91	0.11
AD15BA15	22.22	20.66	7.00	0.20
AD20BA15	20.20	18.24	9.70	0.26

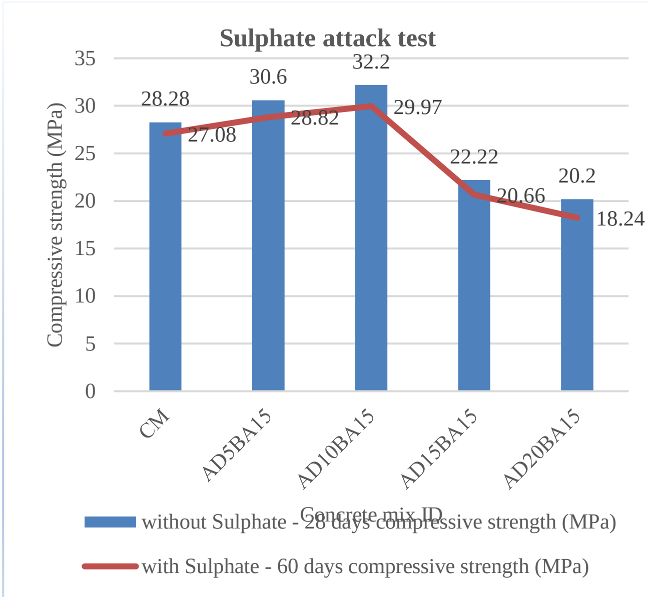

Figure 4: Variation of strength on account of Sulphate attack

E. ALKALINE ATTACK TEST

The alkali hydroxides in concrete may react with aggregates and their constituents if the exposure of the concrete changes for what it has been designed. It may result into alkali-silica-reaction and alkali-carbonate-reaction, forms a gel which is having high affinity for absorption of moisture and based this affinity, may leads to little to more expansion, cracks, pop-outs, colour changes and surface deposits, are inter-dependent on pore structure. Hence, alkalis attack on concrete is a potential source for distress.

The concrete cubes having 150 mm as sides kept for 28 days in water and kept in room temperature for one day to remove the excess engrossed moisture in the samples even after curing in alkaline solution, were immersed in 5% sodium hydroxide solution (NaOH) for 60 days and checked for weight and compressive strength [16]. Very little noticeable change in % loss in weight has been observed in control concrete but for the other mixes, it increased as the % AD increased due to physical deterioration as the outer layer gets degraded for alkaline sodium hydroxide attack. The compressive strength of all the mixes declined as the % AD increased which is mainly because of the solubility of silicate–aluminate hydrated components in hardened concrete and alkali-silica reaction [24].

Table 5: Alkaline attack test on various concrete mixes

Mix ID	28 days compressive strength (MPa) without alkaline attack	60 days compressive strength (MPa) with alkaline attack	% loss in compressive strength	% loss in weight
CM	28.28	26.84	5.10	0.07
AD5BA15	30.60	28.67	6.30	0.09
AD10BA15	32.20	29.88	7.20	0.10
AD15BA15	22.22	20.71	6.81	0.22
AD20BA15	20.20	18.52	8.30	0.31

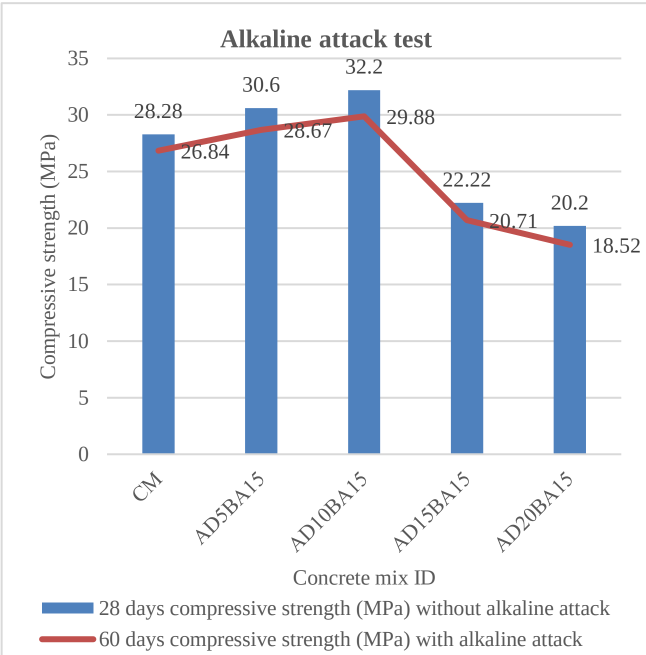

Figure 5: Variation of strength on account of Alkaline attack

4. Conclusions

- Expansion of the concrete cubes and circular molds has been observed which is due to entrapped air of aluminium dross on replacement to cement during cementation process. Hence, 'Aluminium dross' suitable to make light weight building blocks, fabricated panes, and subfloors since it acts as an expanding agent.

- Chloride permeability ratings for all the samples of various replacement levels other than the control mix are low and moderate for the control mix. However, the chloride permeability rating for the AD10BA15 was remarkably close to the medium rating by just 50 coulombs.

- The loss rates in both compressive strength and weight of all the samples increased as the percentage of aluminum dross replaced to cement increased due to acidic attack. However, the percentage losses for AD10BA15 are extremely low when compared with AD15BA15 and AD20BA15 but quite high in comparison with AD5BA15 mix.

- Both compressive strength and weights are reduced with increase in the replacement level of 'aluminum dross' to cement, but anomalies are seen between the two mixes, i.e., AD10BA15 and AD15BA15 for sulphate attack. However, AD10BA15 is found to be better in against sulphate attack in comparison to AD15BA15 and CM since negligible compromise in strength.

- AD10BA15 proved to be a suitable / optimum mix since forfeitures in compressive strength and weight are minimal w.r.t. alkaline attack test.

- Even though the losses like compressive strength and weight increases as the replacement level of aluminium dross to cement increases, variations among two samples is quite negligible for all kinds of tests performed.

- Considering the above facts and the comparison with the control mix because of various durability tests performed, the AD10BA15 mix found to be closer to the CM, hence, the aluminium dross which is a by-product of smelters can be used to replace the cement by 10 % and bottom ash by 15% to sand as optimum dosage to produce cement concrete.

References

1. Aasif M. Baig, Valsson Varghese, Study of properties of coal bottom ash and waste foundry sand and its use in concrete, Lecture Notes on Multidisciplinary Industrial Engineering, (2019) 153-163.
2. Abdullah, Mohamad & A Rashid, Ahmad Safuan & Anuar, U & Marto, Aminaton & Osman, Rasha, Bottom ash utilization: A review on engineering applications and environmental aspects, IOP Conference Series: Materials Science and Engineering. (2019) 527. 012006. 10.1088/1757-899X/527/1/012006.
3. Aldi Vincent Sulistio, Samuel Wahjudi, Djwantoro Hardjito, Processed bottom ash for replacing fine aggregate in making high-volume fly ash concrete, MATEC Web Conf. 138 (2017).
4. Al-Fasih, Mohammed & Ibrahim, Mohd Haziman & Basirun, Nurul & Putra Jaya, Ramadhansyah & Mohd Sani, Mohd Syahrul Hisyam, Influence of partial replacement of cement and sand with coal bottom ash on concrete properties, International Journal of Recent Technology and Engineering. (2019) 8. 356-362. 10.35940/ijrte.C1006.1183S319.
5. Anuar Abdul Wahab, Mohd Fadzil Arshad, Zakiah Ahmad, Ahmad Ruslan Mohd Ridzuan, Mohd Haziman Wan Ibrahim, Potential of bottom ash as sand replacement material to produce sand cement brick, International Journal of Integrated Engineering (Penerbit UTHM). 10 (8) (2018) 38-42.
6. Arimanwa, J. I. et al., Prediction of the compressive strength of aluminum waste–cement concrete using Scheffe's theory, Journal of Materials in Civil Engineering. 24 (2012) 177-183.
7. Arpitha D, Praveen, Kannam, Experimental investigation of aluminium dross and ggbs in the production of eco-friendly concrete, IOP Conference Series: Materials Science and Engineering. 1255. 012003. 10.1088/1757-899X/1255/1/012003 (2022).
8. Arun, N., Singh, P., & Gupta, S, Utilisation of ground bottom ash in concrete, Materials Today: Proceedings. 32 (2020) 663-669.
9. ASTM C267-20; Standard test methods for chemical resistance of mortars, grouts, and

monolithic surfaces and polymer concretes.
10. ASTM C642-97; Standard test method for density, absorption, and voids in hardened concrete.
11. AST C1012-10; Standard test for length change of hydraulic-cement mortars exposed to a sulfate solution.
12. ASTM C1202-07; Standard test method for electrical indication of concrete’s ability to resist chloride ion penetration.
13. ASTM C1202-19; Standard test method for electrical indication of concrete’s ability to resist chloride ion penetration.
14. Augustine U. Elinwa and Elvis Mbadike, The use of aluminium waste for concrete production, Journal of Asian Architecture and Building Engineering. 10 (1) (2011) 217-220.
15. Bai, Yun & Basheer, P.A. Muhammed, Influence of furnace bottom ash on properties of concrete, Proceedings of The Institution of Civil Engineers-structures and Buildings, PROC INST CIVIL ENG-STRUCT B. 156. 85-92. 10.1680/stbu.156.1.85.37888 (2003).
16. B. Vidivelli, R. Divya, An experimental study on the mechanical and durability properties of concrete: partial replacement of fine aggregate with steel slag, manufacturing sand and bottom ash, IOSR Journal of Mechanical and Civil Engineering. 14 (03) (2017) 119-125.
17. Chai Jaturapitakkul, Raungrut Cheerarot, Development of bottom ash as pozzolanic material, Journal of Materials in Civil Engineering (American Society of Civil Engineers). 15 (1) (2003) 48-53.
18. Chen Dai, Development of aluminium dross-based material for engineering applications, M.Sc.Thesis, Material Science and Engineering, Worcester Polytechnic Institute (2012).
19. Diana Bajare, Aleksandrs Korjakins, Mareks Zakutajevs and Filips Voroneko, Applying of aluminium scrap recycling waste (non-metal product, NMP) for production environmental friendly building materials, Vilnius, Lithuania, The 10th International Conference on “Modern Building materials, structures and techniques”. (2010) 13-17.
20. Dilukshan Sritharan, K. Baskaran, J. R. U. C. Jayakody, Study on use of bottom ash in manufacturing cement blocks, Moratuwa Engineering Research Conference (2021).
21. Dr. Evaggelia Petavratzi, Scott Wilson (2007), “A case study, “Residues from aluminium dross recycling in cement”, WRT 177 / WR0115, pp. 1-8.
22. Gert van der Wegen, Ulbert Hofstra, John Speerstra, Upgraded MSWI bottom ash as aggregate in concrete, Waste and Biomass Valorization (Springer Netherlands). 4 (4) (2013) 737-743.
23. Hamzah, A.F., Durability of self-compacting concrete with coal bottom ash as sand replacement material under aggressive environment (2017).
24. H.K. Kim, H.K. Lee, Use of power plant bottom ash as fine and coarse aggregates in high-strength concrete, Construction and Building Materials. 25 (2) (2011) 1115-1122.
25. Indian Standard Codes:
IS 5514:1996 (ASTM C189, 1949); Apparatus used in ‘Le-Chatelier’ test – specification.
IS 12269:2013; Ordinary Portland cement, 53 grade – specification.
IS 2386 (Part III):2002; Methods of test for aggregates for concrete.
IS 383:2016; Specifications for coarse and fine aggregates from natural sources for concrete.
IS 456:2005; Plain and reinforced concrete - code of practice.
IS 10262:2019; Concrete mix proportioning – guidelines.
IS 516:2004; Methods of tests for strength of concrete.
IS 3812 (Part 1):2003; Pulverized fuel ash – specification.
SP 23:1982; Handbook on concrete mixes (based on Indian standards).
26. Malkit Singh, Rafat Siddique, Effect of coal bottom ash as partial replacement of sand on properties of concrete, Journal of resources, conservation and recycling. 72 (2013) 20-32.
27. Mbadike, Elivs M, Effect of incorporation of aluminium waste in concrete matrix using different mix ratio and water cement ratio (2014).