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CIVIL & ENVIRONMENTAL ENGINEERING | RESEARCH ARTICLE

Influence of secondary aluminum dross (SAD) on compressive strength and water absorption capacity properties of sandcrete block

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Abstract: Secondary aluminum dross (SAD) is a hazardous by-product of the aluminum smelting industry. Among various recycling options of this waste, construction and building materials applications is one of the value-added options to end dumping. The present study, thereby, investigates the influence of SAD on the mechanical and durability properties of sandcrete blocks (SBs). Five partial replacements 0%, 10%, 20%, 30% and 40% of river sand with SAD were experimented at constant water–cement ratio of 0.45. Sixty-three SB samples of size 150 mm × 225 mm × 450 mm were molded and cured at different ages of 7, 14 and 28 days before the hardened blocks were subjected to water absorption and compressive crushing tests. The study results revealed that the water absorption of SAD-blended samples was found to rise with increasing percentage replacement with SAD. Also, the study revealed that beyond 10% replacement with SAD, the investigated properties fall below the required limits as stated in relevant standards. SBs blended

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PUBLIC INTEREST STATEMENT

Investigating the possibilities of recycling aluminum waste into a construction material is the aim of this research. Aluminum waste is considered a hazardous waste capable of affecting human health when ingested and contributes to environmental degradations. Possible health hazards associated with this waste include but not limited to lung and bladder cancer, neurological disorder, respiratory difficulties, nausea, vomiting and coughing. When sent to landfills, leaching tendencies are manifested culminating to contamination of groundwater and reordering of ecological balance. In a bid to overcome these challenges, the reuse of stabilised aluminum waste as a partial replacement for sand in sandcrete blocks (SBs) production becomes significant. Rising demand of natural sand from other contending uses broaden the scarcity and subsequent price increases of natural sand in construction industry market. SBs play pivotal roles in construction projects accounting for more than 90% of walling materials used in Nigeria due to its relative economy, stability and durability merits.

with SAD up to 10% of weight of sand could be beneficial for construction economy, healthy living, ecological and sustainable built environment.

Subjects: Engineering Management; Materials Science; Chemical Engineering; Civil, Environmental and Geotechnical Engineering

Keywords: Aluminum dross; construction project; replacement; sandcrete block; sustainability

1. Introduction

It is becoming increasingly difficult to ignore the relevancies of SBs in the construction industry. The relevancies could be seen in the general acceptability, durability and minimal maintenance attributes in building development projects and in particular, as walling and partition elements (Ajao et al., 2018; Ojo, 2016). It has been shown that over 90% of buildings in Nigeria utilize SBs for its construction while the use cut across many African countries and beyond (Baiden & Asante, 2004; Abdullahi, 2005; Oyekan & Kumiyo, 2011; Anosike & Oyebade, 2012). SB is majorly a mix ratio 1:6–1:8 of cement, fine aggregate (river, pit sand) and water with or without admixtures molded in specified sizes (Anosike & Oyebade, 2012; Nigerian Industrial Standard [NIS] 87:2007). British European Standards (BS EN 772-2:1998) defines block "as a heterogeneous building material with a unit of larger size in all dimensions than specified for bricks but no dimension should be more than 650 mm nor should the height be greater than its length or six times its thickness". Similarly, Nigerian Industrial Standard (NIS 87:2007) describes SBs as walling components which when placed in its standard position exceeds the sizes specified for bricks. Two load bearing hollow SBs sizes specified by NIS 87 (2007) are of dimensions 450 mm × 225 mm × 225 mm and 450 mm × 225 mm × 150 mm. According to this classification, 150 mm and 225 mm thicknesses required web thickness of 37–50 and 50 mm, respectively.

Within the two major materials (cement and sand) used in SB production, natural sand occupies a higher volume of about 86% in the finished product. Ameh, Ajaja and Ogunde (2015) posit issues of increasing demand of natural sand from other competing uses further the shortage and subsequent price increases of natural sand in construction industry market. Amid other promising alternative materials that can be used to replace natural sand either partially or wholly for SB production is aluminum dross (AD). With continuing exhaustion of natural sand residues, rising cost, increased construction activity, strict mining regulations and environmental damages, it becomes necessary to explore AD as a material in production of SB. The present study was undertaken to investigate the characteristics of secondary aluminum dross (SAD) and the engineering properties of SB produced from SAD as alternative to natural sand.

2. Literature review

AD is one of the residual by-products that is generated from aluminum refining and smelting processes. The major constituents of AD are aluminum, aluminum oxides, and different salts in varying compositions (Murajama et al., 2012). Primary dross with associated names (white dross, wet dross and rich dross) and secondary dross (black dross, dry dross and lean dross) are two types of dross produced from either primary or secondary refining of aluminum (Mahinroosta & Allahverdi, 2018a; Liu, Leong, Hu, & Yang, 2017). Primary dross is stuffed in metal content with about 80% by weight of the total dross obtained from aluminum ingots as raw material (Meshram & Singh, 2018). On the other hand, secondary dross has low metal content of about 5–20% of the weight of the dross obtained from scraps smelting. Additionally, black dross has higher salt content, gas evolution than white dross and granular in shape. Galindo et al. (2015) and Liu et al. (2017) detailed SAD to be hazardous waste that is very combustible, nuisance, poisonous and seepable in accordance with European Catalogue for hazardous waste. Liu et al. (2017) suggest that AD should be treated before landfilling. The treatment according to the authors involves aqueous dissolution at 60°C for 48 h to reduce its reactivity. This combined hydrolysis and heat treatment can convert dross to inert material. Further stabilization can be accomplished with gypsum. It is of researchers' view that the quantity of dross generated is a function of the type and quality of raw material, operating condition, type of technology and furnace used.

Previous studies by Tsakiridis, Oustadakis, & Agatzini-Leonardou (2014); Dai & Apelian (2017); and Mahinroosta and Allahverdi (2018a) have shown that globally over one million metric tons of white dross and about five million metric tons of black dross are generated annually. Within this production range, higher percentage (95%) is reported to be landfilled around the factory vicinity (Adeosun, Sekunowo, Taiwo, Ayoola, & Machado, 2014; Oresanya, Ben-Enukora, Omojola, Oyero, & Amodu, 2017). According to Mahinroosta and Allahverdi (2018a), production of AD by regions in metric tons indicates that US generate 800,000 tons with 3–4% increment per year and 900,000 tons of salt cake respectively followed by UK at 200,000 tons while India generate 75,000 tons. The cost implications of about 80 million euro for the disposal of aluminum waste is reported in UK (Meshram & Singh, 2018; Murayama et al., 2012). The authors pointed out that for each ton of aluminum produced, about 1.5–2.5% and 8–15% of white and black dross are produced respectively.

The increasing production of this waste calls for new dimensions to prevent disposal in landfills with potential health risk, ecological and safety hazards due to poisonousness and great combustible tendencies. Meshram and Singh (2018) and Liu et al. (2017) note that the when dross come in contact with water, a hazardous gas like ammonia is generated which pollutes the atmosphere and may lead to explosion in alkaline environment. Similarly, they assert that effluents from tertiary aluminum treatment industries contains chemicals like Na^+, Ca^{2+}, Mg^{2+}, K^+ and $N–NH_3$ with manifestation of heavy metal precipitation when these chemicals are disposed in water-bodies. Aquatic organisms are affected by the toxic ammonia oxidation declines in the lowering circumstances at the bottom of water bodies. For groundwater effects, Meshram and Singh (2018) note that PH level drops to about 4 due the action of bacteria that breaks down ammonia which is highly unfavorable due the disposal of nonmetallic products. The contamination of soil and groundwater is also pronounced in the nearness of tertiary aluminum treatment plants. The contamination of water composition around the landfill's sites, disturb plant and animal lives, furthering the reordering of ecological balance.

Oresanya et al. (2017) pointed out that dust particles and fumes from aluminum waste can cause lung and bladder cancer, immunity and neurological disorders in extreme cases due to the presence of carcinogen like hexavalent chromium. Another health risks associated with exposure to dross is the risk of dementia of Alzheimer's diseases and cardiovascular diseases which is characterized with slow decline in memory, reasoning and thinking ability. Further health risks include respiratory tract infection, coughing, respiratory difficulties, nausea, vomiting and diarrhea if ingested. Hence, active solutions to reduce the ecological impacts of AD become paramount in wake of health and environmental degradation possibilities associated the material.

Among various recycling options of AD in literature, construction and building materials applications is one of the value-added options to end dumping (Mahinroosta & Allahverdi, 2018a). Applicability in construction and building materials is in concrete production, alumina cement production, filler in asphalt, non-aerated concrete, concrete bricks and tiles (Mahinroosta & Allahverdi, 2018b). Correspondingly, the authors noted volume of waste reduction, conforming disposal cost and diminished environmental pollution as benefits derivable from construction and building materials applications of dross. This suggests that any innovation in converting industrial waste to building material and components has the ability to improve the construction industry performance with reduced environmental impact.

Experimental studies on physical, mechanical and durability properties of concrete and SBs with cement and natural sand substituted with AD have been a subject of debate in academic journals.

For example, Shinzato and Hypolito (2005) evaluated engineering properties of concrete blocks produced with up to 33% replacement of sand with AD. Their findings indicate that the blocks blended with AD at a limit satisfied dimension, humidity and absorption tests but failed compressive strength test. However, their results revealed that one of the constituents of AD accelerated the strength development of samples occasioning to the decrease in working time. Elinwa and Mbadike (2011) analyzed the compressive and flexural strengths of concrete produced with dross at 5%, 10%, 20%, 30% and 40% replacement intervals by cement weight. Their results showed 10% optimal replacement of AD with cement when compared with the control mechanical properties. In another dimension, Bajare, Kazjonovs, and Korjakins (2013) studied the feasibility of incorporating SAD for the production of lightweight expanded clay aggregate (LWeCA) and lightweight concrete. Results indicate propensity of producing LWeCA with SAD and a lower mechanical strength of concrete produced with LWeCA from SAD.

Adeosun et al.'s (2014) study compared two grain sizes (106 and 184 μm) of SAD obtained from Aluminum Rolling Mill, Ota, Ogun state, Nigeria, in producing refractory bricks. They evaluated properties such as volume shrinkage, apparent porosity, bulk density, cold crushing strength and permeability of the designed samples. Results establish that 106 μm size SAD performed better than 184 μm size AD in physical properties evaluations while cold crushing strength showed a lower strength of 940 kN/m^2. Acid refractory bricks made with 106 μm size SAD was proposed by the authors due the comparable properties with medium-alumina fireclay refractory bricks. In the same vein, Reddy and Neeraja (2016) investigated the compressive, split tensile, flexural strengths, sorptivity, water absorption and rapid chloride in concrete blended with AD. At 15% replacement of AD with cement, the evaluated samples showed a better result in all the tests performed against control. The study proposes the blending of AD in concrete matrix for production of paver blocks, refractory bricks and for normal strength concrete. Mailar et al. (2016) examined the mechanical and durability properties of concrete mixed with AD in hot weather condition. At 20% replacement with cement, the investigated samples exhibit superior mechanical and durability properties than the normal concrete. Dai and Apelian (2017) investigated the use of two types of AD (primary and secondary) as a refractory material reinforcement in mortar. The investigation characterized compressive and flexural strengths of the design samples. The results indicate 40% increase in flexural strength and 15% increase in compressive strength at 10% replacement with sand under primary AD. Javali et al. (2017) studied the use of AD and granular iron slag as partial replacement for sand and cement respective toward producing eco-friendly concrete. They evaluated the compressive strength and durability properties of M4 grade concrete at 5%,10%,15%, 20% substitution of cement and 10%, 20%, 30% and 40% substitution of sand. At 5% and 20% substitution of AD and iron slag with cement and sand, compressive strength and durability properties were found to comply with conventional concrete. Further result on toxicity analyses reveals less significant effects of salts and gasses on the concrete mix. López-Alonso et al. (2019) found aluminum waste at controlled amount to be a suitable aggregate in road construction when mixed with recycled aggregate and mixed recycled aggregate. They found improved mechanical behavior when aluminum waste is mixed with recycled aggregate and mixed recycled aggregate in road construction.

The purpose of the present study is to investigate the characteristics of SB where the fine aggregate (sand) is partially substituted with up to 40% SAD. This will validate which of the previous assertions is accurate or not. The objectives are to determine the grade size distribution, water absorption capacity of SB blended with SAD and the compressive strength of the resultant SB.

3. Materials and methods

3.1. Materials

3.1.1. Secondary aluminum dross

The SAD also known as black dross used in this study was obtained from Aluminum Rolling Mill (Tower Aluminum) industrial layout Ota, Ogun state, Nigeria. In-depth study of the chemical properties of the SAD obtained at Aluminum Rolling Mill, Ota, was undertaken by Adeosun et al.

Table 1. Chemical composition of aluminum dross

Element	SiO_2	CaO	Na_2O	Al_2O_3	Fe_3O_3	MgO	SO_3	K_2O	Al
Composition (%)	7.17	0.07	0.06	63.34	0.03	0.04	0.03	0.01	28.77

Adapted from Adeosun et al. (2014).

(2014) and represented in Table 1. No treatment was given to the acquired sample and therefore used as was obtained from the factory.

3.2. Cement

Dangote 3X of grade 42.5 N Portland cement was used for this research work complying with standard of Nigeria Industrial Standard NIS 441:1 (2004) and BS EN 933-1 (1980) for cement classification, manufacturing, distribution and usage.

3.3. Sand

River sand (SD) used for this research was gotten from river Ogun at Abeokuta in Ogun State. It was sharp, clean, and free from clay and organic matter and well graded and satisfied the requirement stated in BS EN 1997:1 (2004).

3.4. Water

The research used clean water meant for consumption as specified by BS EN 100 (2002) within the concrete laboratory of Department of Building Technology, Covenant University, Ota.

3.5. Methods

This research adopted design mix of 1:6 (one part of cement and six parts of sand) and was batched by weighing method. The river sand was partially replaced with SAD at varying percentages—10%, 20%, 30% and 40% respectively in order to determine the durability and strength parameters in the SB production. Before the SBs production, preliminary test such as sieve analysis was conducted in order to determine the physical characteristics of the materials. Ogunbayo et al. (2018) argued that fine aggregate should be entirely rid of clay and silt contents. The batching, mixing of materials and production of 150mm thick SBs were manually carried out and cured by sprinkling of water before the whole samples were crushed at different age regimes. The water–cement (w/c) ratio used for the mixing was 0.45. The compressive strength of the samples was determined at 7, 14 and 28 days based on field experience. Ajao et al. (2018) conveyed that bulk of the block manufacturers in South Western Nigeria vended their blocks within the first 7 days of production without attaining maximum strength. Water absorption tests were carried before the compressive strength of the SBs was conducted.

Tools and apparatus such as head pan, shovel, digital weighing balance, compression testing machine, wheel barrow, curing tank, digital sieve shaker and 150 mm × 225 mm × 450 mm steel SB mould were used for the experiment. The experimental procedure put into consideration the safety recommendations of Ogundipe et al. (2018). Materials, equipment and SBs samples used and prepared in the present study are shown in Plates 1–6.

4. Results discussion

4.1. Water absorption measurements

The water absorption test was carried out on the samples after maximum attainment of curing period for 28 days in accordance to BS 6431-11, EN 99 (1983/1991). W_1 and W_2 refer to as dry weight and wet weight respectively as shown in eq. (1). The results were presented in Table 2.

$$\frac{W_2 - W_1}{W_1} \times \frac{100}{1} \qquad (1)$$

Plate 1. Secondary aluminum dross (AD) sample.

Plate 2. River sand (SD) sample.

Plate 3. Mixture of aluminum dross and river sand.

Plate 4. Portland cement.

Plate 5. Sandcrete block produced from (SAD and RD).

Plate 6. Compression testing machine loaded with sample.

4.2. Water absorption

Cementitious product durability is usually affected by water penetration, gases and attacking chemicals which is depended on the microstructure and porosity properties. Thus, this study experimentally investigated on the test samples the durability property of water absorption of SAD SB. The transfer of different solutions across concrete ensues not singly by flow via the porous structure but similarly by diffusion and absorption (Mailar et al., 2016). The results for water absorption are as shown in Table 2. The mean values of water absorption for the specimen 20% SAD, 30% SAD and 40% SAD are greater than specified requirements of 12% (BS EN ISO 10545, 1997). It was only 10% SAD block samples that had significant value of 9.40% and less susceptible to absorption. The possibility for this behavior could be linked to non-workable mortar with w/c ratio of 0.45 resulting to more water requirements as the percentage of SAD increases and expansion tendencies of AD. This implies that SBs substituted with more 10% of SAD exposed to dampness will tend to soak up more water and this will ultimately deteriorate the strength of masonry units as pointed by Oyekan and Kamiyo (2011).

4.3. Grain size distribution

Combined SAD and river sand results for the sieve analysis are shown in Figure 1. The two samples of both AD and river sand fell within the overall fine and coarse grading limit according to BS EN 12620:2002 + A1:2008 (2002/2008) +A1 (2008). However, the fineness modulus of river sand and SAD were analyzed and gotten to be 3.50 and 3.13 respectively indicating SAD to be finer than the river sand.

Table 2. Water absorption measurements of 150 mm× 225 mm × 450 mm secondary aluminum dross sandcrete blocks

S/n	% Replacement of dross	Specimen A (%)	Specimen B (%)	Specimen C (%)	Average (%)	Standard deviation
1	10	9.90	7.70	10.50	9.40	1.47
2	20	20.60	14.70	8.60	14.60	6.00
3	30	14.30	13.90	16.70	15.00	1.51
4	40	11.80	14.70	20.60	15.70	4.48

Figure 1. Sieve analysis of secondary aluminum dross and river sand as fine aggregates.

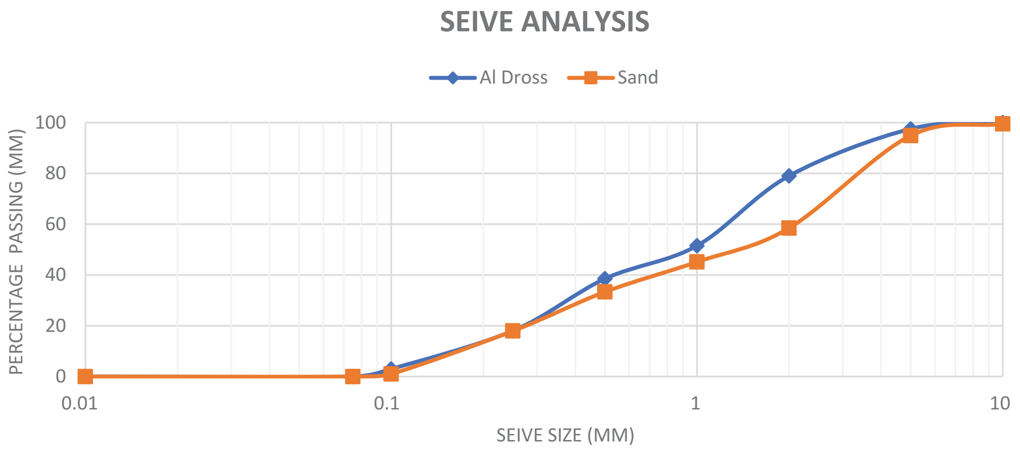


Figure 2. Compressive strength of SAD-blended sandcrete block.

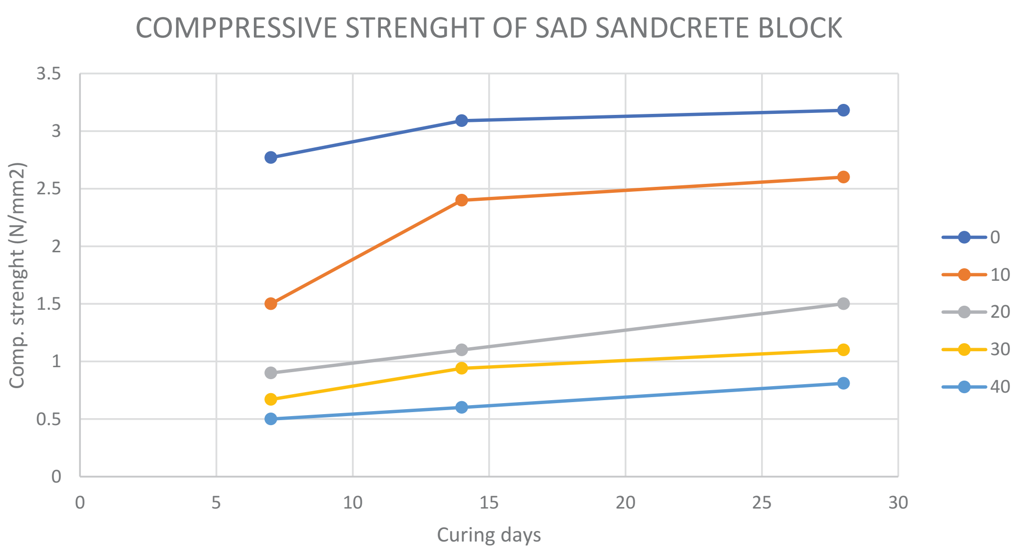
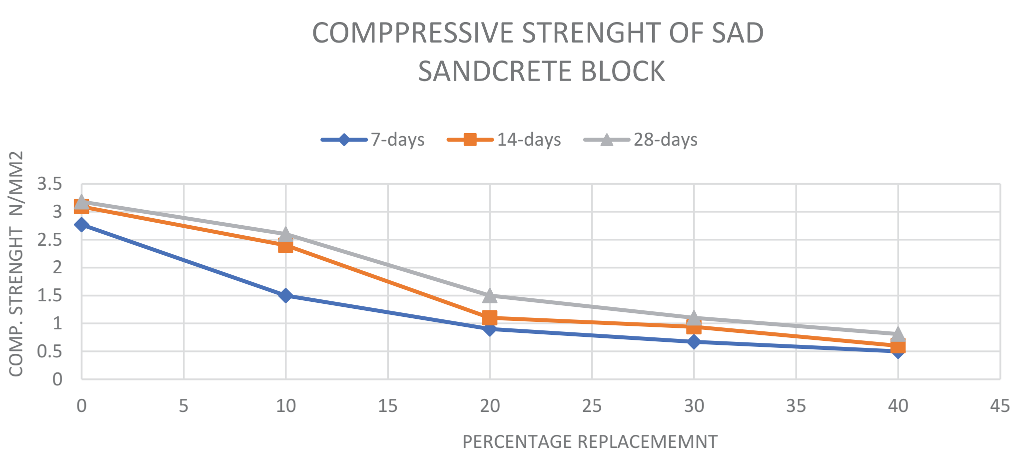


Figure 3. Compressive strength of SAD-blended sandcrete block.



4.4. *Compressive strength*

The results for the compressive strength of the SAD SBs are shown in Figures 2 and 3, respectively. Figure 2 shows the percentage replacements of samples in strength against the curing days while Figure 3 depicts the curing days of the samples in strength against the percentage replacement. These test results showed the compressive strength of SAD SBs at 0%, 10%, 20%, 30% and 40% replacement ranged between 2.53–3.65, 1.50–2.50, 0.90–1.50, 0.70–1.10 and 0.50 –0.81 N/mm^2 at design mix of 1:6. The values obtained from SBs at 10% replacement with SAD satisfied minimum standard for hollow SBs (150 mm × 225 mm × 450 mm) meant for load bearing at minimum specification of 2.5 N/mm^2(Bajare et al., 2013). With 10% replacement, the specimen attained 26% increase in compressive strength between 7th and 14th day and 15% increase in compressive strength between 14th and 28th day, respectively. These results corroborate with the findings of Elinwa and Mbadike (2011) of 10% optimum replacement of untreated SAD in concrete application. However, 20%, 30% and 40% replacement SAD blocks compressive strengths decreased below the required standards. It has been shown that the finer the aggregate in a mortar mix the more the propensity to absorb more water (Neville & Brooks, 1987). The lower compressive strength could be related to increases in w/c ratio of the mortar as the SAD content increases resulting to formation of pores in hydrated SAD SBs paste. However, the strength results for 20% and 30% SAD SBs indicated a promising application in non-load bearing walling units such as in fencing, partitioning and parapet walls purposes due to low margin to stipulated standards.

5. Conclusion

The compressive strength and water absorption capacity properties of SBs blended with SAD have been investigated for likely application in construction and building material units. River sand has been substituted with SAD at varying percentages. From the results, it was noted that up to 10% substitution of SAD, there is no substantial decline in compressive strenght and water absorption tendencies of the investigated samples. The main findings from the study are reported as follows:

- The addition of SAD presents less workability for the same w/c ratio as that of mortar matrix without SAD. This behavior is attributed to higher specific surface area and expansive nature of SAD and subsequent absorption of water in the mix required for sustaining workability.
- The water absorption was found to be increasing with the percentage replacements with SAD and is considerable for larger substitution.
- The compressive strength decline with increasing SAD substances. There appears to be void creation in the SAD mortar mix as the percentages of SAD is increased resulting to lower compressive strength.

SBs blended with SAD up to the stipulated limits will promote economy, healthy living, ecological and sustainable-built environment.

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