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Research article

Development of lightweight structural concrete with artificial aggregate manufactured from local clay and solid waste materials

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ABSTRACT

The partial replacement of conventional natural coarse aggregate (NCA) with artificial light weight aggregate (LWA) manufactured from local clay and solid waste to develop a lightweight aggregate concrete (LWAC) for the structural use was studied in this paper. Red clay and Savar clay were used individually with solid wastes like rice husk ash (RHA) and waste glass to produce LWA. The suitability of raw materials and LWA was evaluated by investigating various properties. The mechanical, thermal and durability properties of manufactured LWAC were explored. The results of physical, chemical, thermal and geotechnical properties revealed that Red clay is better than Savar clay for the preparation of LWA. All the physical and mechanical properties of LWA prepared from Red clay are suitable for the preparation of LWAC compared to Savar clay. The test results demonstrated that the concrete manufactured by replacing 30 % of NCA with LWA produced a concrete of lightweight properties. The compressive strength of LWAC for 7 and 28 days was observed as 28 and 48 MPa, respectively. The results of modulus of elasticity, splitting tensile strength, flexural deformation, and creep test of LWAC revealed that these mechanical properties meet the requirements for the structural concrete. The RCP test proves that chlorine permeability of LWAC is comparable with NCA. It was observed that the superior performance of LWAC can be achieved only when the optimized mix designed is followed strictly. The suitability of the replacement of natural aggregate by LWA may be helpful for Bangladesh due to the scarcity of natural coarse aggregate and reusability of solid waste materials.

1. Introduction

Concrete, a common material, is widely used in the field of construction building industries and is composed of four basic natural ingredients like sand (as fine aggregate), water, cement, and pebble (as coarse aggregate) [1]. The consumption of huge quantities of natural aggregates per year [2] in concrete industries over the world is not environmentally benign activity [3] where this industry has economic, social and ecological effect [4]. The extraction of sand threatens the existence of rivers and continuous collection of gravel is

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the most disastrous activity for natural environment [5,6]. The use of industrial by-products and wastes in concrete combination can be a promising substitute to achieve ecological improvement of the concrete manufacturing industries [7]. The application of such concrete which is known as light weight aggregate concrete (LWAC) made up of using industrial wastes and by-products can be contemplated an environmentally benign building material in the structural and civil engineering field which can grant a better excellence of life for all living being [8]. The LWAC is less dense concrete which allows to lessen overload of structures, footing proportions, measurements of slabs, columns, and beams [9]. Its consequences availability of more space in building and reduces the overall cost of the construction. Moreover, usage of LWAC offer better thermal insulation properties and improved fire resistance because of its reduced heat transfer behaviour. Natural aggregates (diatomite, limestone, pumice, volcanic cinders, etc.) and artificial aggregates (perlite, clay, polystyrene/other polymeric materials, shale, glass, slate, plastic grains etc.) both are used in manufacture of LWAC. The addition of so many industrial wastes and by-products such as geopolymer [10], fly ash [11,12], waste glass [13], biochar [14] in concrete manufacture as lightweight aggregate (LWA) have been intensively explored for sustainable purpose. The use of slate, clay, shale, industrial slag in the manufacture of LWAC reduces the overload of building and improves the durability in tough environments because of lower stiffness and uniform strain distribution at micro level [15]. High strength LWAC making is possible using agricultural solid wastes like oil palm shell (OPS) which is hard and form strong physical interaction with cement paste [16]. The usage of OPS waste to manufacture of LWAC is more sustainable in the construction sector due to requiring optimum energy for preparation and adequate compressive strength.

Several investigations on LWAC made up of using different types of LWA have been published. Usage of expanded clay expanded silica, and pumice aggregate in manufacture of LWAC showed higher strength, greater mechanical, and fire resistance behaviour than other LWA [17–22]. The application of natural aggregate in making concrete is becoming detrimental all over the world due to its high-density [23]. Considering the whole weight of the high-rise construction is very fundamental in planning the foundation in the matter of weak territory. LWAC is a promising alternative for low weight and shock resistance constructions [24]. Therefore, application of improved LWAC became a vital requirement for structural engineering now a days and is a difficult science and challenging to achieve the preferred parameters with optimum cost. However, it is significant to investigate LWAC to identify the advancement of using new wastes and aggregates for construction. Therefore, the present research work offers the use of rice husk ash and waste glass as solid waste materials along with local clay as substitution of both fine and coarse aggregate in making LWA and LWAC with its encouragement on various properties. The clay has been collected from those type of local barren land that is not very good for agriculture production. Using of this type of natural clay as one of the ingredients of preparing LWA will not create any harmful issue for sustainability of environment. Additionally, the use of waste glasses also takes the recyclability of garbage and cleanliness of environment a step further. The use of rice husk ash as another waste material makes this method more feasible and economic because plentifully production of rice paddy increases the availability of rice husk ash with negligible cost in Bangladesh. Due to high silica content rice husk ash can be a good pozzolanic admixture for making concrete [25]. Moreover, the presence of rice husk ash improves compressive strength and decreases the erosion of concrete caused by the rough climate [26–28]. Using local clay and waste glass as raw materials for manufacturing the LWA along with rice husk ash would improve several properties of LWAC. To examine the quality of the prepared LWAC, several properties such as density, splitting tensile strength, water absorption, drying shrinkage, flexural strength, thermal conductivity, chloride ion permeability has been investigated. The correlative study of mechanical properties between ordinary weight concrete and prepared LWAC has also been investigated in this research work. Instruments such as furnace, oven, mixer machine etc. and tools used in preparation and processing of LWA and LWAC are very simple, low priced, and very common in availability all over the world. Additionally, the combination of ingredients clay-glass/rice husk-sand/stone in making LWAC improves the required properties of concrete material on the subject of strength and durability. Moreover, the use of the prepared LWA for the partial replacement of natural aggregate in making LWAC would decreases the weight of the concrete material that lowers the damaging effect regarding heavyweight. Therefore, quicker manufacture, easy handling, and low energy consumption have made the procedure environmentally benign. The concluding results of the prepared LWAC offer better strength to mass ratio efficiently with lower overall cost than that required for steel and concrete with natural coarse aggregates.

2. Materials and methods

2.1. Materials

Raw materials used in this study are Red clay, Savar clay, rice husk ash (RHA), and waste glass. Two clays, namely Red and Savar clays have been used individually with waste glass and RHA to produce the lightweight aggregates (LWA) for this study.

2.1.1. Collection of clay materials

The selection of clay sampling sites was guided by several factors such as the existence of geological surveys and historical information on clay deposits within the region, and consultation with the local geologists and soil scientists. The red clay sampling site is chosen since it is well-documented to suit ceramic and construction purposes, based on previous research conducted in the region. The site of the clay sample of Savar was chosen because of its reputation in geological literature for having desirable clay properties, particularly in terms of plasticity and sintering behaviour. Clay samples were collected with the help of a combination of hand auguring and soil coring techniques, ensuring a variation in the depth of samples collected. Red clay was collected at 0–30 cm depth from Pallabi thana under Mirpur section-12, Dhaka (23°49′27.1"N 90°22′21.0"E). On the other hand, Savar clay was collected at 0–50 cm depth from Nayarhat area under Savar thana of Dhaka district (23°54′45.1"N 90°14′01.4"E).

2.1.2. Collection of solid waste materials

Physical and chemical characteristics of rice husk ash and waste glass are considered as part of the solid waste for the production of light weight aggregates (LWA). Rice husk ash is a pozzolanic material and is known for its high silica content, which makes it reactive and gives lightweight aggregates a better sintering behaviour and mechanical strength. In this work, rice husk ash was collected from the rice mills of Louhajang thana under Munshigonj district (23°28′46.9"N 90°18′39.2"E).

The low density and high melting point offer the waste glass, on the other hand, as an advantage in the sintering process for the use as a fluxing agent. Waste glass was collected from a local glass industry (PHP Float Glass Industry Ltd) (22°19′24.2"N 91°48′36.0"E) of Chittagong district.

In addition, silica sand was obtained from Chunarughat thana of Habiganj district (24°13′23.4"N 91°30′29.0"E). Ordinary Portland cement (OPC) was collected from MI Crown Cement Ltd. Bangladesh. Natural coarse aggregate (Limestone) was sourced from Habiganj district. The images of all raw materials are shown in Fig. 1.

Limitations in sampling processes, such as accessibility, time, and natural variability in clay composition, can introduce uncertainty in data interpretation, despite efforts to ensure representativeness.

2.1.3. Sample preparation

Silica Sand: The sand samples were prepared by collecting, cleaning, washing, drying, and separating them into particle size fractions.

Natural Coarse Aggregate (Limestone): The limestone samples were prepared for analysis and formulation through various steps, including collection, crushing, grinding, homogenization, drying, particle size analysis, chemical and mineralogical analysis, and quality control.

Glass powder: Glass cullet samples were collected, cleaned, crushed into powder, sorted, homogenized, and chemically analyzed to ensure accurate characterization and suitability for application.

Rice Husk Ash: Rice husk ash samples were prepared for analysis and formulation by following these steps: they were collected, cleaned, dried, burned in a furnace, cooled, and ground or milled.

Red clay and Savar clay: Clay samples are collected, dried, ground, sieved, mixed, homogenized, and stored for testing and formulation.

2.2. Expanding agent and binding material

Na_2CO_3 was used as expanding agent to prepare lightweight aggregate. It helps to lower the softening temperature of the glass phase and promotes expansion at even lower temperatures during sintering. A 5 wt% of Na_2CO_3 was used for the preparation of LWA. Polyvinyl alcohol (PVA) was used as a binder for the preparation of LWA and it was used 2 wt%.

2.3. Physical properties

The physical properties of raw materials were evaluated by the gradation of them in different sizes. Sieve analysis or a gradation test is an important method for assessing the particle size distribution of granular material. The particle size distribution is presented in Fig. 2.

The particle size distribution of rice husk ash, clay, and sand can affect the properties of lightweight aggregates significantly. The particle size distribution of clay can impact the strength and performance of the aggregates. [Fig. 2] shows that most of the rice husk particles are smaller than 0.6 mm, with around 20 % being even smaller than 0.2 mm. Red clay has a wider particle size distribution than rice husk, with a significant portion of particles falling between 0.2 and 2.0 mm whereas the Savar clay particles are larger than 0.4 mm, with a significant portion being even larger than 1.0 mm. The fineness of rice husk ash plays a crucial role in improving the pozzolanic properties of the lightweight aggregate [29]. The density, moisture content, water absorption and specific gravity were also

Fig. 1. Raw materials for preparing of lightweight aggregate.

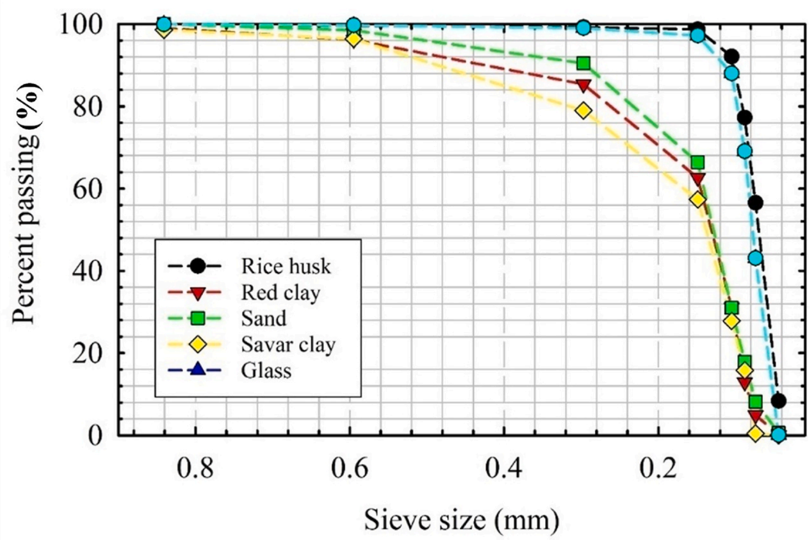


Fig. 2. Sieve analysis of raw materials (Rice husk, Red clay, Sand, Savar clay, and Glass).

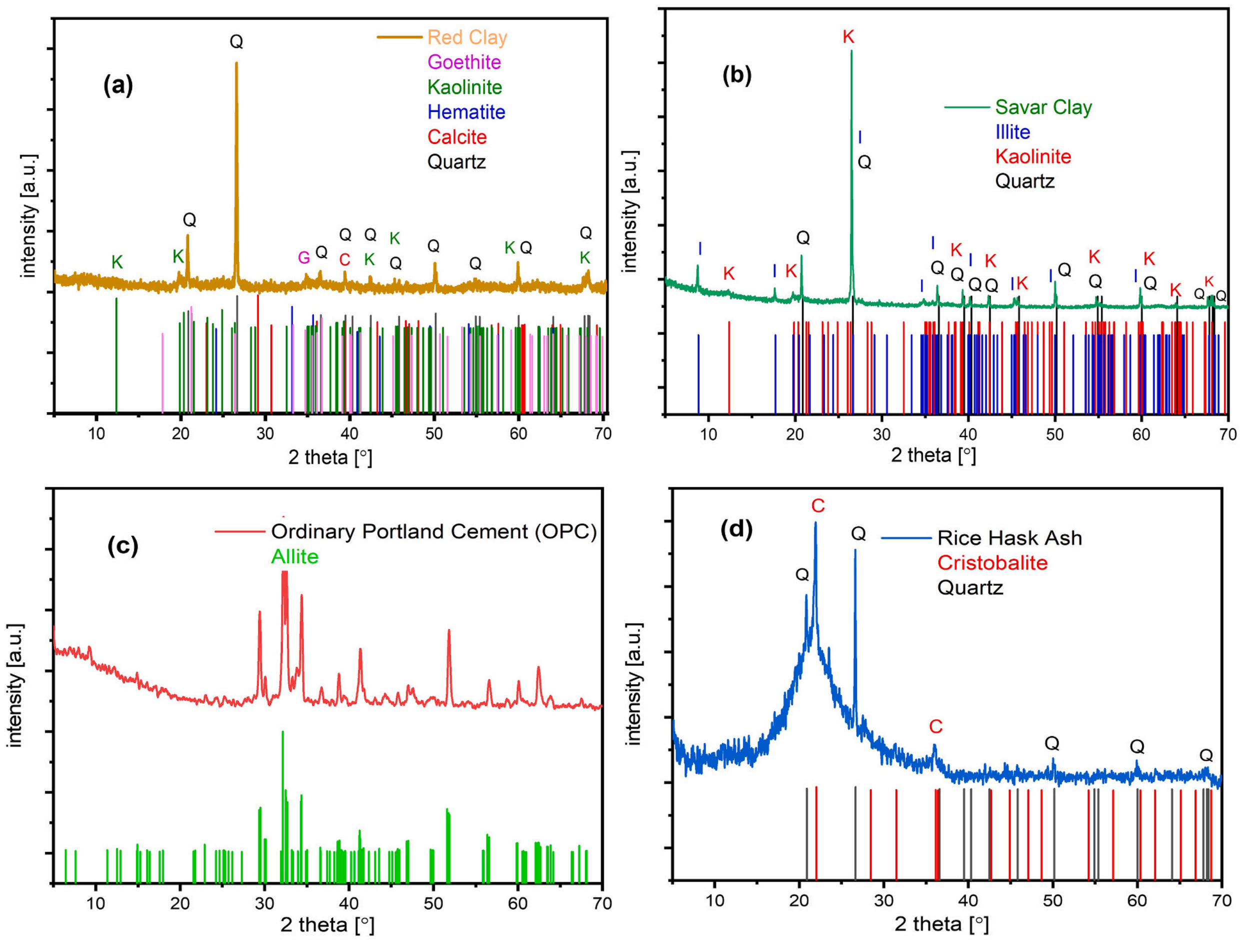


Fig. 3. X-Ray diffraction spectra of (a) Red clay, (b) Savar clay, (c) Ordinary Portland Cement (OPC) and (d) Rice husk ash (RHA) at ambient temperature.

evaluated and shown in Table 1.

2.4. Chemical properties

Chemical compositions of collected raw materials and solid wastes were investigated by using Wavelength Dispersive X-ray Fluorescence, WDXRF (Model no: Rigaku ZSX primus IV) presented in Table 2.

Red clay shows the composition as SiO_2, Al_2O_3, Fe_2O_3 and CaO as shown in Table 2. The colour of Red clay is slightly reddish due to the presence of significant portion of iron (~6 %). The chemical component of Savar clay is SiO_2, Al_2O_3 and K_2O. Major chemical component of rice husk is silica. The key chemical components of OPC is CaO, SiO_2, Fe_2O_3. Glass powder primarily contains SiO_2 and CaO.

2.5. Mineralogical properties

The mineralogical composition of the clay samples and raw materials was studied using powder X-ray Diffraction (XRD) (SmartLab SE, Rigaku, Japan) with Cu K-alpha radiation ($\lambda = 1.540598$ Å), at a scan rate of 30°/min, and step size of 0.02°. The diffraction patterns obtained were analyzed using HighScore software. The American Mineralogist Crystal Structure Database was used to identify the peaks by comparing them to standard patterns of the following minerals: Quartz(amcsd-0006212), Calcite(amcsd-0017869), Alite (amcsd-0017753), Cristobalite(amcsd-0020745), Dolomite(amcsd-0006032), Goethite(amcsd-0004539), Hematite(amcsd-0021166), Illite(amcsd-00050150), Kaolinite(amcsd-0020861).

The XRD analysis shows that Red clay contains quartz, kaolinite, goethite and hematite as shown in Fig. 3 (a). The quartz and kaolinite minerals are particularly well-suited to produce bricks, pottery, and other ceramic products [30].

The crystalline phases of Savar clay are kaolinite, quartz and illite Fig. 3(b). Kaolinite is a clay mineral that is known for its fine particle size which would make it difficult to produce a lightweight coarse aggregate with the desired porosity [31].

The presence of kaolinite and illite in the clays was confirmed using XRD, where distinct diffraction peaks corresponding to these minerals were observed. For kaolinite, the characteristic peaks at approximately 12.4° and 20.8° 2θ (corresponding to the 001 and 002 planes, respectively) were noted. Illite showed peaks around 8.9° and 17.8° 2θ, indicative of its 001 and 002 reflections.

The reflection near 25°2θ is commonly attributed to the (001) plane of illite and the (002) plane of kaolinite. The coexistence of those minerals is due to their structural similarity and close basal spacing. The presence of mixed-layer clays may lead to peak shifts or changes in peak intensities, strongly depending on the relative proportions of either mineral and the degree of interstratification between the two. Alite is the most intense peak in OPC which is also the dominant phase Fig. 3(c)). Rice husk ash is present as quartz and cristobalite form Fig. 3(d).

The absence of sharper peaks in the XRD analysis of RHA indeed suggests a predominantly amorphous structure. The amorphous nature of rice husk ash (RHA) significantly influences the pozzolanic activity within the concrete matrix [32]. Typically, the high amorphous silica content in RHA reacts with the calcium hydroxide produced during cement hydration to form additional calcium silicate hydrate (C–S–H), which is beneficial for the strength and durability of concrete.

2.6. Thermal properties of clay

Thermo-gravimetric analysis (TGA)

TGA was used to assess the thermal stability and decomposition characteristics of the materials. Analysis was performed using STA 449, NETZSCH for measuring the TGA. In TGA, mass loss is determined by the increase in temperature in a multifunctional process (isothermal or dynamic). The temperature was ramped from 25 °C to 1000 °C at a heating rate of 10 °C/min under a nitrogen atmosphere to prevent oxidation. Weight changes in the sample were recorded as a function of temperature. TGA analysis of Red clay shows peaks at 100 °C, 399 °C, and 700 °C, indicating the presence of free water, dehydroxylation of clay minerals, and decomposition of organic matter in (Fig. 4).

The gradual weight loss up to 100 °C in the TGA of Savar clay is due to the evaporation of free water, followed by a more rapid weight loss up to 500 °C, attributed to the decomposition of organic matter and dehydration of bound water. The minimal weight loss above 500 °C suggests the decomposition of carbonates and other minerals. The stability and uniform composition of Red clay make it suitable for high-temperature applications, while the rapid weight loss and formation of defects in Savar clay make it less suitable for engineering applications.

Table 1
Physical properties of raw materials.

Parameter	Savar clay	Red clay	Rice husk ash	Waste glass	OPC
Bulk Density (kg/m^3)	1620	1780	103	1340	1400
Moisture content (%)	16.32	15.84	13.58	0.06	0.31
Water Absorption (%)	28.94	24.58	2.34	–	–
Specific gravity	1.81	1.65	1.90	2.11	3.14

Table 2
Chemical composition of Red clay, Savar clay, Rice husk ash and Glass powder and Ordinary Portland Cement (OPC).

Component	SiO_2	Al2O3	Fe_2O_3	CaO	MgO	Na_2O	K_2O	SO_3	TiO_2	Loss on Ignition (LOI)	Insoluble Residue (IR)
Red clay	57.05	17.28	6.03	7.08	1.71	1.46	1.78	1.35	0.673	5.54	–
Savar clay	64.24	9.35	1.81	2.59	3.33	2.2	5.38	2.13	0.582	8.38	–
Ordinary Portland Cement (OPC)	21.00	4.95	3.52	65.15	1.39	0.03	0.72	1.74	–	1.19	0.31
Rice husk ash (RHA)	88.74	0.76	0.24	0.18	0.54	1.6	3.23	1.07	0.09	3.55	–
Glass powder (GP)	79.05	1.54	0.12	4.96	0.62	13.1	0.34	0.18	0.085	–	–

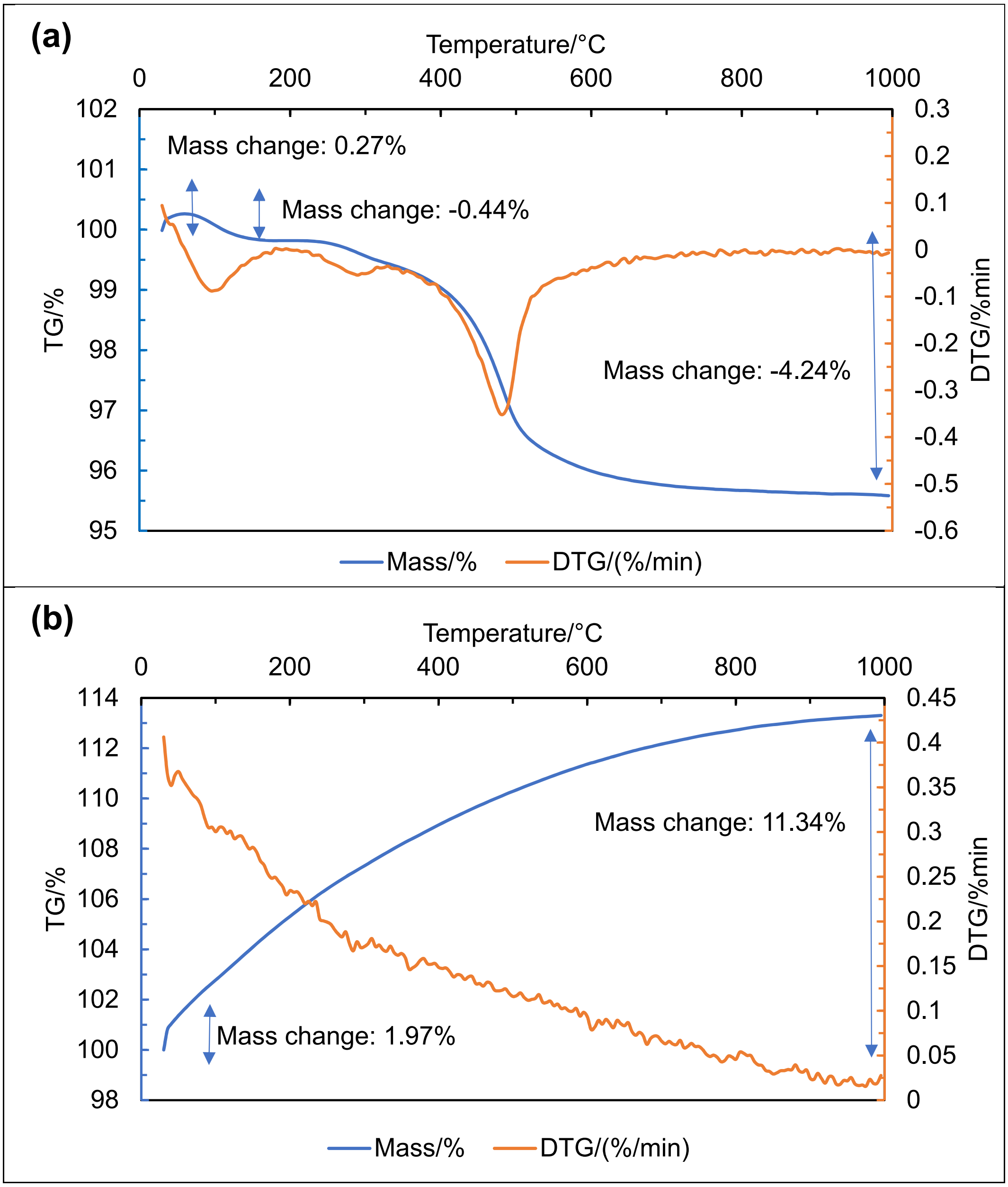


Fig. 4. Thermogravimetric analysis (TGA) of (a) Red clay (b) Savar clay at ambient temperature.

2.7. Differential scanning calorimetry (DSC)

The differential scanning calorimetry analysis of Red clay and Savar clay provides insightful data on their thermal properties and stability. The DSC measurements was carried out using STA 449 F5 Jupiter, NETZSCH performed at a heating rate of 10 °C/min. DSC measures the enthalpy change for its physical or chemical changes in the materials as a function of temperature or time.

The DSC curve of Red clay illustrates two key thermal events: the loss of physically adsorbed water and the dehydroxylation of kaolinite, with mullite formation at higher temperatures [33]. On the other hand, the DSC curve for Savar clay displays distinct thermal characteristics, including organic matter decomposition, bound water dehydration, carbonate decomposition, and sintering (Fig. 5).

The high-water absorption of Red clay enhances concrete mix workability, while meta kaolinite's pozzolanic activity boosts concrete strength and durability. However, the endothermic peak between 100 °C and 500 °C in Savar clay could induce aggregate

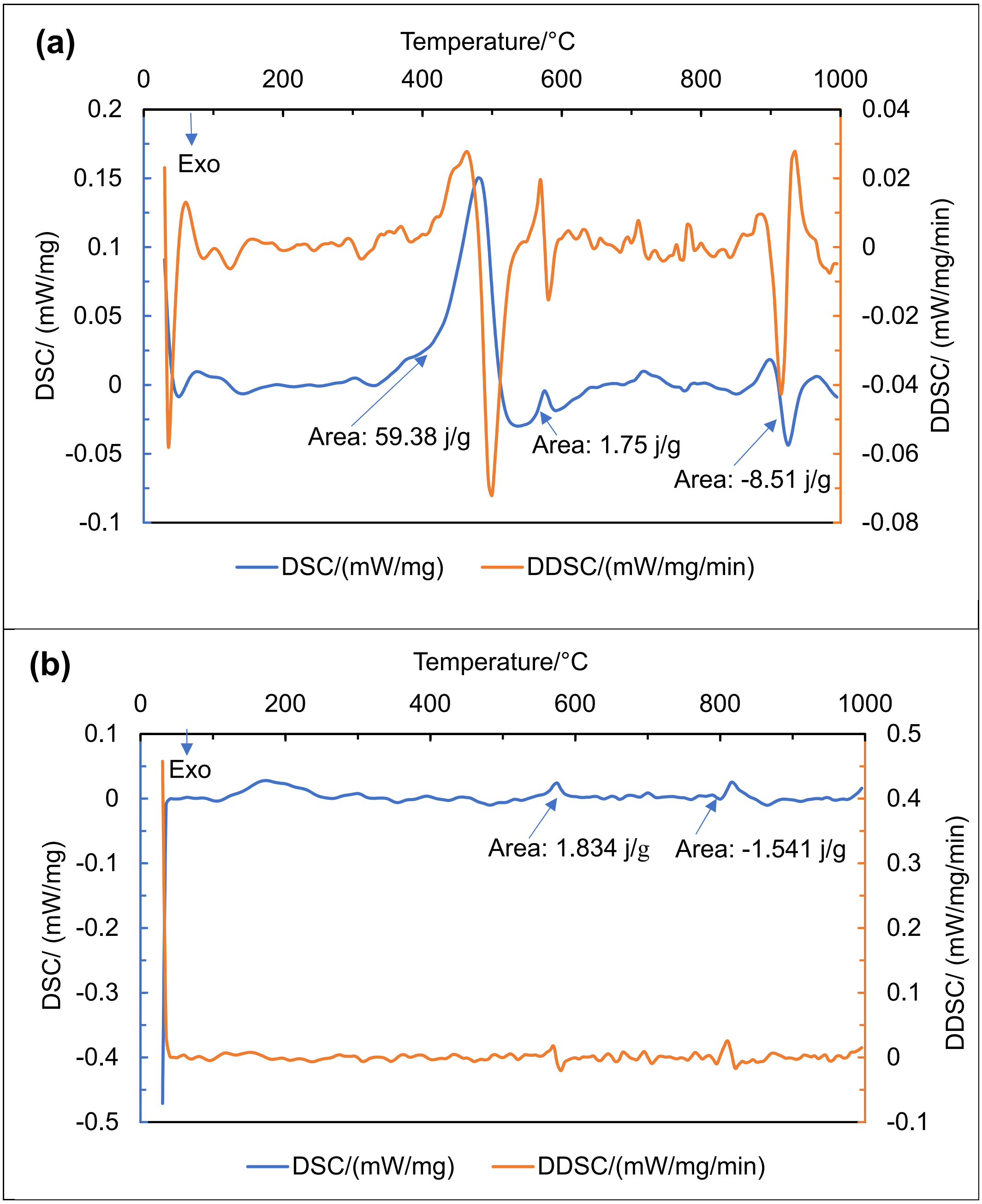


Fig. 5. Differential Scanning Calorimetry (DSC) spectra of (a) Red clay and (b) Savar clay at room temperature.

defects like cracks due to gas release during organic matter decomposition, potentially slowing aggregate sintering and reducing strength (Table 3).

The investigation of geotechnical properties reveal that Savar clay is a more clayey soil than Red clay since Savar clay has a higher liquid limit, plasticity index, and activity/clay factor. Due to higher free swell index Savar clay is more likely to shrink and swell than Red clay. The higher activity/clay factor Savar clay indicate that it is more dispersive than Red clay. Savar clay may not be suitable for use in foundations or embankments where shrink-swell or dispersive behaviour is a concern [34]. Therefore, Red clay may be a more suitable choice for the engineering applications.

2.8. Preparation of light weight aggregate

The production of lightweight coarse aggregates involved using high-quality clay (50 %), rice husk ash (20 %), waste glass powder (15 %), an expanding agent (10 %), and a binding agent (5 %). Clay provided plasticity and binding properties, rice husk ash enhanced the lightweight properties, and waste glass powder enhanced strength and stability.

At first, the cullet or broken glass was gathered and processed into a powder. Pulverized next was the ash from the rice husks. Ball milling was used to grind the raw materials, which included clay, rice husk ash, and powdered glass powder. The grinding duration varied for each raw material as they all needed to be able to pass through a 150-μm (100 mesh no.) sieve. In the case of materials, grinding is important for two key reasons: first, fineness—indispensable for the sintering process; second, quality of the final aggregate.

The necessary quantity of water and binding agent were added to the entire mixture after ball milling. The necessary size of granules was achieved by granulating this combination. The targeted particle size for Lightweight aggregate within 9.50–10 mm which meets the corresponding standard specifications such as ASTM C330 and C331 for structural and masonry lightweight aggregates. The clay pebbles were first left to dry naturally for 24 h after granulation, and then they were dried for a further 24 h in a laboratory oven set at 110 °C.

After the granules had dried in the oven, they were heated in a Muffle Furnace to a temperature of 1000 °C. The soaking time was retained at 180 min, and the heating rate at 5^{0}C/minute for 3 h. The items were cooled and kept after being fired. The detailed flow diagram of the production process is shown in Fig. 6, and the resulting lightweight coarse aggregate using Red clay and Savar clay is shown in Fig. 7.

One typical way to make lightweight construction materials is to use lightweight aggregates. Lightweight aggregates, which replaced the natural coarse aggregate and fine aggregate, reduced the density of concrete due to the air gaps in them.

2.9. Preparation of light weight aggregate concrete

LWAC was prepared by adding varying amounts of LWA to the coarse aggregate ranging from 10 % to 50 %, while keeping the overall mixture ratio consistent. The mixing was conducted manually on a flat surface using a shovel. The process involved combining cement and sand in a mortar mixer, then incorporating LWA and crushed coarse aggregate (CA). Water was added periodically to ensure even mixing. The resulting mixture was molded into cylinders of 200 mm height and 100 mm diameter. These cylinders were formed in three layers; each layer was compacted using a steel rod before adding the next. After 24 h in the molds, the structures were moved to a curing tank filled with clean water maintained at 25 °C. The compressive strength was assessed after 7 days and again at 28 days. Water cement ratio (W/C) was maintained 0.45 for preparing concrete mixture and the mixing ratio of cement:sand:coarse aggregate was optimized to 1: 1.67: 2.62 for concrete mix design(Fig. 8).

2.10. Testing techniques

Water Absorption Test: Water absorption of Lightweight aggregate and Concrete was measured in accordance with ASTM C642-13 (2013). **For Light weight concrete**, cylinder specimens of 100 × 200 mm were used for the testing of water absorption at 7 and 28 days of aging. The sample mass was measured in air under various conditions, i.e., oven dry, surface dry after water immersion, and surface dry after water immersion and boiling. The apparent sample mass was measured in water after immersion and boiling.

The percentage of water absorbed is calculated by the following formula: $(C - A)/(C - D) \times 100$.Where, A = mass of oven-dried sample in air, g.

B = mass of surface-dry sample in air after immersion, g.

Table 3
Geotechnical properties of Red clay and Savar clay.

SL	Physical Parameter	Savar clay	Red clay
01	Liquid Limit (LL or W_L) [From Semi Log Graph]	37 %	31 %
02	Plastic Limit (PL or W_p)	13.11 %	9.47 %
03	Plasticity Index (PI = LL – PL)	23.89 %	21.43 %
04	Liquidity Index (LI) =(W-PL)/(LL-PL)	1.61 %	1.08 %
05	Free Swell Index (%) = $[(V_d - V_k)/V_k \times 100$ % Where, V_d = Volume of soil from dist. Water cylinder. V_k = Volume of soil from Kerosine cylinder.	1.74 %	1.39 %
06	Activity/Clay Factor	0.98 %	0.71 %

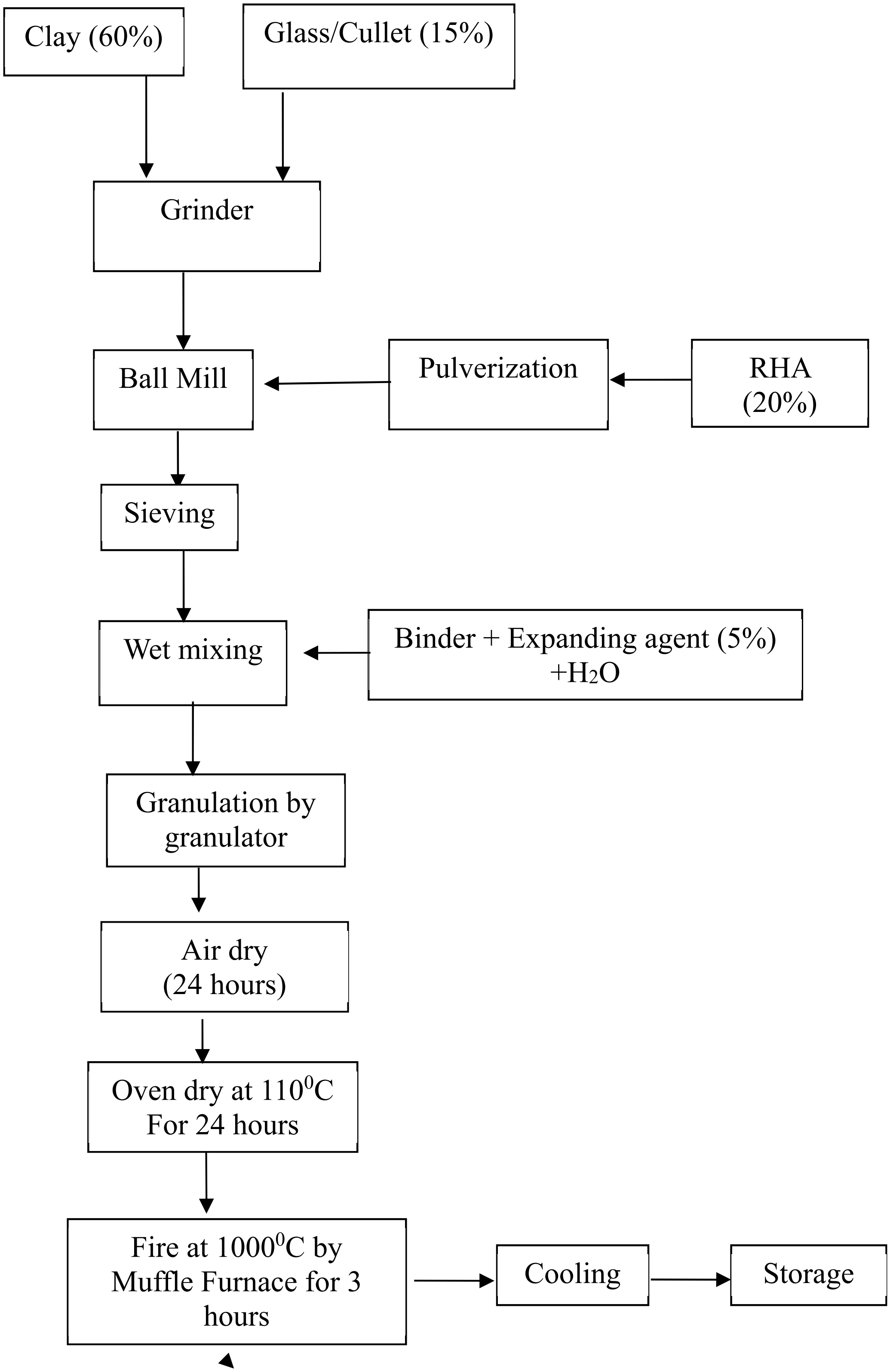
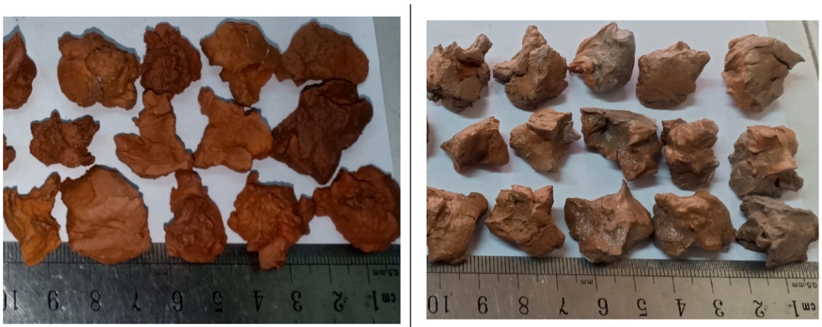


Fig. 6. Flow diagram of the production of artificial lightweight coarse aggregate.



(a) (b)

Fig. 7. Lightweight coarse aggregate prepared using (a) Red clay, and (b) Savar clay.

Fig. 8. Lightweight aggregate concrete (LWAC) prepared by the partial replacement of NCA by LWA prepared from Savar clay (L) Red clay (R).

C = mass of surface-dry sample in air after immersion and boiling, g.

D = apparent mass of sample in water after immersion and boiling, g.

Bulk Density and Apparent Porosity of LWA: **The bulk density and apparent porosity of the aggregates were measured using the Archimedes immersion technique, which involves submerging the sample in boiling water according to ASTM C20-00.**

Aggregate crushing value: The aggregate crushing value was determined using the method described in ASTM C131/C131M-20. The test involved subjecting the aggregate to a compressive load until it fractured, and then measuring the percentage of fines produced.

Fineness modulus: Fineness modulus was determined using the method described in ASTM C136 -19. The test involved sieving the aggregate through a series of standard sieves and calculating the cumulative percentage retained on each sieve.

Density of LWAC: The density of the concrete block was determined using the method described in ASTM C 567, which involves measuring the mass and volume of the clay samples.

Compressive Strength: Test specimens were prepared and cured according to the method described in ASTM C39. Cylindrical shape specimens of size 100 × 200 mm were used. This test method covers the determination of compressive strength of cylindrical concrete specimens such as molded cylinders. The compressive strength of the specimen was calculated by dividing the maximum load attained during the test by the cross-sectional area of the specimen. The compressive strength of the concrete was determined at 7 and 28 days of age of curing by using hydraulic press machine (Hydraulic press: CARVER laboratory press, model no. C25576, USA) and Hounsfield UTS 10 KN (model: H10KS Hounsfield, UK) respectively.

Thermal conductivity: The thermal conductivity of lightweight concrete was measured by using a Lee's Disc apparatus based on ASTM D5930-16 (2016). The tests were conducted at 28 days of aging over oven dried 100 × 100 × 100 mm cube samples. Quick thermal conductivity meter (QTM-500) was used to study thermal conductivity behavior of the LWA concrete mixes. Each sample was subjected with three repetitive experiments of thermal conductivity with minute standard deviation (less than 3 %) [35].

Splitting tensile strength: The splitting tensile strength test was performed by an average of eight specimens. Cylindrical specimens of 152 by 305 mm were prepared in accordance with ASTM C 192. Curing and testing was carried out according to ASTM C496 (2016). The specimens were loaded in a universal testing machine (M-500-30 KNCT) and the load was applied at a constant rate until failure occurred. The splitting tensile strength was calculated by using the following equation:

$$\sigma t = 2P / \pi DL$$

where:

σt is the splitting tensile strength (MPa)

P is the applied load at failure (N)

D is the diameter of the specimen (mm)

L is the length of the specimen (mm)

Dry shrinkage: Drying shrinkage of hardened concrete prisms of 75 × 75 × 285 mm was carried out by employing method described in ASTM C157/C157M − 08 using three specimens. The specimens were removed from the mold after 24 h from the addition of water to the cement during mixing operation. Upon removal of the specimens from the molds, they are placed in lime-saturated water maintained at 25 °C for 28 days ($t_{0,}$ initial curing period). The initial length of each specimen was measured at the end of curing period (t_0). Then the specimens were transferred into the laboratory humidity cabinet where the temperature was maintained at 25 °C, and the relative humidity was controlled at 55 %. The length of each specimen was measured again at 7 and 28 days (t) after curing period(t_0) for measure the drying shrinkage.

Dry Density: The dry density of hardened concrete was determined in accordance with BS EN 12390–7:2009. Three cylindrical specimens of 152 by 305 mm (6 by 12 in.) were prepared, cured, and tested following the specified standard. The average dry density of the three samples was reported as the result.

Fresh Density: The fresh density test of freshly prepared concrete mixes was conducted according to ASTM C138.

Rapid Chlorine Permeability test (RCPT): Chloride ion penetration was performed with the cylindrical concrete of 50 × 100 mm in accordance with ASTM C1202-12. Three cylindrical specimens measuring 50 × 100 mm were prepared and tested following the ASTM C1202-12 standard and average results are recorded.

3. Results and discussion

3.1. Physical properties of aggregates

The physical parameters of LWAs were investigated to optimise the LWA production and to achieve the appropriate performance characteristics. The physical properties like bulk density, particle density, water absorption, specific gravity, aggregate crushing value, unit weight, fineness modulus and particle size were measured for NCA and prepared artificial LWA using Saver clay and Red clay (Table 4).

It has been observed that the density of LWAs is lower than NCA. The lower density of LWA offers making low weight concrete. Moreover, the strength of the LWA is higher because of its higher crushing value than that of NCA (limestone). LWA blends with cement more firmly due to its hydroscopic nature and shows better hardening of concrete because of satisfactory hydration by absorbed water [34]. Overall, Table 4 shows that LWA is significantly lighter than normal weight aggregate, but it also has higher water absorption and is less resistant to crushing. The average size of the lightweight aggregate prepared from Red clay and Savar clay is 9.60 and 9.83 mm which is finer than natural coarse aggregate and meet the standard ASTM C330 and ASTM C331.

3.2. Density

It has been shown that the density of the concrete mixes reduces with the increasing amount of LWA because of the low specific gravity of LWA (Fig. 9).

All concrete mixes containing 20–50 % LWA have density less than 2000 kg/m^3 and could be considered as lightweight concrete [36].

3.3. Water absorption and porosity of LWAC

Porosity measures the size of interstices which can enclose fluids compared to the overall size of the concrete. The access of

Table 4
Physical properties natural coarse aggregate (NCA) and Lightweight aggregate (LWA).

Parameter	NCA (Limestone)	LWA with (Savar clay)	LWA with (Red clay)	ASTM C330, C331
Maximum Dry Loose Bulk Density (kg/m^3) Combined fine and coarse aggregate	1649	930	926	1040
Particle Density (kg/m^3)	1927	1530	1424	–
Water Absorption (%)	2.34	28.94	24.58	–
Specific gravity	2.9	1.81	1.65	–
Aggregate crushing value (ACV)	<30	28.72	28.72	–
Unit weight (kg/m^3)	1770	1050	986	–
Fineness Modulus	5.30	2.11	2.50	–
Particle size (mm)	11.68	9.8 3	9.60	–

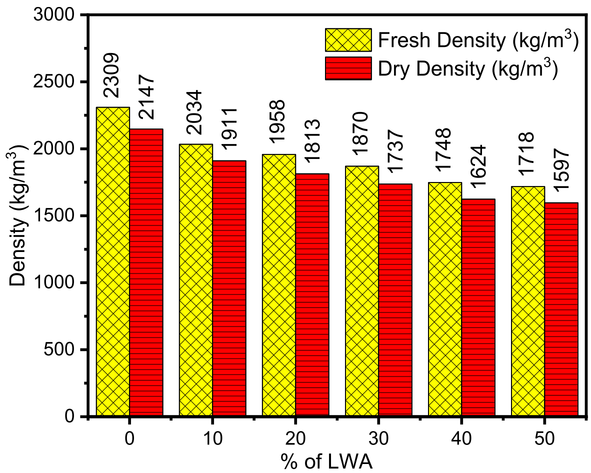


Fig. 9. Effect of Light Weight aggregate (LWA) on the density of concrete.

corrosive agents into pores is liable for different complications for durability of concrete. Nonetheless, compressive strength is decreased with increasing porosity. It has been observed that the amount of absorbed water of the concrete containing LWA was regularly increased with increasing the amount of LWA in concrete mixes. This is because higher hydroscopic nature of the prepared LWA than limestone. It was previously stated that the use of artificial aggregates as a substitute of natural aggregate increased hydroscopic nature of concrete [37] and in some cases the water absorption was more than 10 % in LWAC [38]. Earlier studies suggest that good quality concretes have water absorption less than 10 % by mass in general [39]. In other ways, high quality concretes showed less than 5 % absorbed water usually [40]. In this investigation, it has been showed that even though the combination of LWA in concrete increased the amount of water absorption, the combination up to 40 % of LWA with Red clay and 30 % of LWA with Savar clay showed the absorption of water less than 10 % (Table 5).

3.4. Drying shrinkage

During the hardening of concrete mixtures, the evaporation of capillary water results drying shrinkage that causes shrinking and crack formation within the concrete. It was reported earlier that there is a relation between modulus of elasticity and drying shrinkage [39,41] with increasing modulus of elasticity the concrete shows decreasing drying shrinkage. With the addition of LWA in concrete mixes drying shrinkage usually increases because of lower value of elastic modulus and high-water absorption nature of LWA [42–44]. The shrinkage behaviour of concretes depends upon the composition of the cement paste. The removal of water inside from the tiny capillary apertures causes volume change significantly during drying of concretes [45]. The shrinkage of concrete during drying has been affected considerably by the degree of hydration [46]. It has been shown that with increasing LWA drying shrinkage of the concrete mixes reduced with considerable modulus of elasticity (Table 6).

Therefore, the LWAC are constructed with reasonable water to cement ratio accompanying good capable of being worked showing substantial drying shrinkage.

3.5. Compressive strength of LWAC

Based on the data provided in Table 7 the compressive strength indeed increases when 30 % LWA is added to the concrete mix for both Red clay and Savar clay types.

This observed behaviour can be attributed to several factors: Lightweight aggregate concrete (LWAC) typically has a lower density than natural coarse aggregates like crushed coarse aggregate (CA). When they replace part of the Natural coarse aggregate (NCA) in the

Table 5
Water absorption and porosity of LWAC.

Serial	% of LWA in Concrete mixture	Water Absorption of LWAC		Porosity of LWAC	
		7 days	28 days	7 days	28 days
1	0	0.61	0.91	1.48	1.73
2	10	3.07	3.84	5.09	5.28
3	20	4.78	5.69	6.94	7.42
4	30	5.50	7.53	8.72	9.96
5	40	7.31	9.16	10.68	13.87
6	50	8.85	10.40	14.56	17.24

Table 6
Variation of drying shrinkage and modulus of elasticity of LWAC with the different amount of LWA used in the concrete mixes.

Composition in %	Drying Shrinkage (Micro strain) × 10^{-6}		Modulus of Elasticity (GPa)	
	7 days	28 days	7 days	28 days
0	228	388	27.8	31.24
10	207	319	22	25.30
20	188	310	17	20
30	156	263	13.40	16
40	121	205	10	12
50	102	203	8	9.10

Table 7
Compressive strength of LWAC with various percentages of LWA.

Serial No.	Concrete mixing ratio	% of LWA added	Compressive strength (Red clay) MPa		Compressive strength (Savar clay) MPa	
			7 days	28 days	7 days	28 days
1	Cement: Sand: Coarse	0	29	50	Normal concrete (Coarse aggregate)	
2	1: 1.67: 2.62	10	24	38	27	31
3	Water cement ratio (W/C) ratio: 0.45	20	25	39	21	34
4	Water admixture (W/A) ratio:0.5	30	28	48	23	35
5	Admixture added: 2 % wt.% of Cement)	40	19	40	20	37
6	Mold Shape and size: Cylinder shape and Size: Diameter:100 mm, Height: 200 mm	50	18	37	17	34

mix, they fill the interparticle voids more effectively, leading to a denser packing of the concrete matrix. This denser packing translates to better load distribution and higher compressive strength [47,48]. The rougher surface texture of LWAC compared to smooth Natural coarse aggregate (NCA) provides stronger interfacial bonding with the cement paste. This improved bond allows the aggregates to effectively share the applied load, resulting in increased resistance to crushing [49]. LWACs have lower thermal expansion coefficients than normal Natural coarse aggregate (NCA). This translates to reduced internal stresses in the concrete during temperature fluctuations. Lower internal stresses contribute to higher overall strength and improved crack resistance [50]. The lower density of LWACs leads to a lighter concrete mix. This can be beneficial for applications where weight reduction is crucial, such as high-rise buildings or bridges. While compressive strength is considered, important to ensure other properties like flexural strength and shear strength are also adequate for the specific application [51]. However, it is true that excessive LWA replacement (beyond a certain optimal percentage) can lead to a decrease in compressive strength.

While LWAs are generally lighter than conventional aggregates, they may have inherently lower individual strength compared to some Natural coarse aggregate (NCA). As the LWA content increases, the overall strength of the concrete matrix gets diluted, leading to a potential decrease in compressive strength [52]. With a higher LWA proportion, the surface area of the aggregates contacting the cement paste increases. While this might seem beneficial for bonding, it can also lead to thinning of the cement paste film around each aggregate. This thinner film may not be strong enough to effectively transfer the applied load, compromising the overall strength of the concrete. Higher LWA content introduces more voids into the concrete matrix. These voids can act as stress concentration points and weaken the material under compression. Additionally, excessive water absorption by LWCAs can further lead to porosity and internal micro-cracks, further impacting strength [52]. Densely packed natural aggregates create an interlocking mechanism within the concrete matrix that contributes to its strength. As the LWA content increases, the interlocking effect diminishes, reducing the ability of the aggregate to resist compressive forces. High LWA content can make the concrete mix less workable and increase the difficulty of proper placement and compaction. This can lead to inhomogeneities and voids within the hardened concrete, further affecting its compressive strength [53]. The optimal LWA replacement percentage depends on several factors, including the type and strength of the LWA, the type of cement, the mix design, and the desired application. It is crucial to conduct proper testing and optimization to

Table 8
Splitting tensile strength and flexural strength of ordinary concrete (0 % LWA) and LWAC.

Composition of LWA in concrete mixtures (%)	Ages of Curing (7 days)		Ages of Curing (28 days)	
	Splitting Tensile Strength (MPa)	Flexural Strength (MPa)	Splitting Tensile Strength (MPa)	Flexural Strength (MPa)
0	3.33	2.90	3.71	3.15
10	3.21	2.81	3.50	3.06
20	2.92	2.74	3.15	2.98
30	2.85	2.63	3.09	2.86
40	2.50	2.23	2.90	2.45
50	2.28	1.83	2.47	2.04

determine the optimal LWA content for achieving the desired balance between strength, weight, and other properties. So therefore, compressive strength might decrease with increasing LWA content beyond a certain point.

3.6. Splitting tensile strength

Splitting tensile strength (STS) for all concrete mixtures (Table 8) increased with increasing ages 7–28 days although the changes of STS was reduced as LWA content increased. It has been reported earlier that for LWAC to be consumed in construction building materials, the minimum 28-days necessary STS is 2.0 MPa [54]. Table 8 shows that all concrete mixes containing 0–30 % LWA have more than 2.0 MPa STS.

The replacement of limestone by LWA up to 30 % did not change STS markedly for all ages. The decreasing STS was noteworthy for the concrete containing 40 % LWA at 7 days ages and getting improved with growing age of the concrete at 28 days. It is remarkable to observe that a substantial progress of STS was detected after 7–28 days for concrete mix containing 40 % LWA, whereas enhancement for other mixtures was small. Generally, the engineers use steel support to carry the ductile loading. But in some constructions like airfield and highway slabs, pavements, etc., it is unreasonable to usage steel reinforcement. Therefore, a consistent value of STS of concrete is much important to avoid the creation of cracks which may produce stability and serviceability difficulties and consider the safety of the constructed structures in seismic loading [55,56].

3.7. Flexural strength

As the percentage of lightweight aggregate (LWA) in the concrete mix increases, there is a general decrease in the flexural strength of the concrete at both 7 days and 28 days of curing. This indicates that the addition of LWA tends to reduce the concrete's resistance to bending or flexing. At 0 % LWA, the flexural strength starts at 2.90 MPa (7 days) and increases to 3.15 MPa (28 days). With increasing LWA content, the reduction in strength is gradual but noticeable [57]. For instance, at 50 % LWA, the flexural strength drops to 1.83 MPa at 7 days and 2.04 MPa at 28 days. At both curing periods, the trend is similar; however, the flexural strength at 28 days is consistently higher than at 7 days for the same LWA composition. This is expected as concrete typically gains strength over time due to the continuing hydration of the cement [58] The use of LWA can be beneficial for reducing the weight of structures and for certain applications where high flexural strength is not critical. However, for structural applications where flexural strength is crucial, such as in beams, slabs, and load-bearing elements, a high percentage of LWA might not be advisable.

3.8. Thermal conductivity of the LWAC

The average value of thermal conductivity of LWAC with two different clay, Savar clay and Red clay was recorded in Table 9.

For normal weight concrete, the thermal conductivity is in the region of 1.98–2.94 W/(m. K) [59]. The thermal conductivity of the samples was found to be within the range of 0.5–0.6 W/mK, indicating good insulation properties. Due to high porosity of LWA the concrete mixes showed lower thermal conductivity than that of ordinary concrete because of the presence of air [60]. The use of LWA makes suitable thermal condition for concrete mixes contributing ecological development. These results suggest that the curing process significantly affects the thermal conductivity of the material, with longer curing times resulting in lower thermal conductivity values.

3.9. Creep test

The creep test curve shows the amount of creep strain that occurs in concrete over time under a sustained load where the load is 30 MPa (Fig. 10).

Concrete creep refers to the phenomenon in which concrete deformation increases with time under long-term external load [61]. The prove curve shows the relationship between stress and strain in concrete. The creep test curve for the Natural coarse aggregate (NCA) 70 % + AG 30 % composition concrete shows that it has a lower creep strain than the other curves. This means that the concrete will deform less under a sustained load. The prove curve for the Natural coarse aggregate (NCA) 70 % + AG 30 % composition concrete shows that it has a higher modulus of elasticity than the other curves. This means that the concrete is stiffer and will deform less under a given load. The lower creep strain and higher modulus of elasticity of the Natural coarse aggregate (NCA) 70 % + AG 30 % composition concrete indicate that it will have better performance than the other concretes. This is because it will be less likely to deform under sustained loads, which can lead to cracking and other problems. In addition, the Natural coarse aggregate (NCA) 70 % + AG 30 % composition concrete is likely to have a higher strength than the other concretes [62]. This is because the aggregate content is higher, and aggregates are generally stronger than cement paste. Overall, the creep test curve and prove curve indicate that the Natural coarse aggregate (NCA) 70 % + AG 30 % composition concrete will have better performance than the other concretes.

3.10. Chloride ion permeability

The most common, simple, and quick method to evaluate the penetrability of chloride ion into concrete is the rapid chloride permeability test (RCPT) [63]. RCPT measures electrical responses of concrete's capability to inhibit chloride ion infiltration. Chloride ion penetrates from environment into the concrete and can lead to corrosion in RCC structure. Therefore, it is very important to investigate chloride ion permeability which can disturb the durability of concrete. Generally, chloride ion has very insignificant effect on the structural strength of concrete at very low concentration. In case of high concentration (more than 1 % by mass of cement)

Table 9
Thermal conductivity of lightweight aggregate concrete blocks and natural coarse aggregate (NCA) concrete block.

No	Parameter Name	Age of concrete block	Block size and Shape in mm	Result		
				Lightweight aggregate concrete (Red clay)	Lightweight aggregate concrete (Savar clay)	Concrete block with natural coarse aggregate
1.	Thermal Conductivity [W/mK]	28 days	(100x100x100) mm, Cube	0.69	0.72	0.84

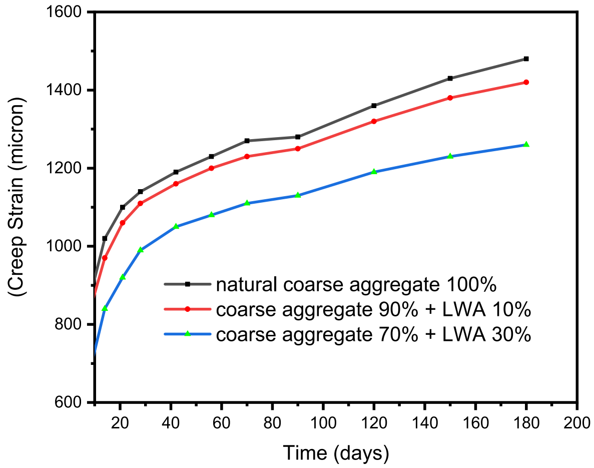


Fig. 10. Creep test curve of Concrete prepared by LWA under a sustained load.

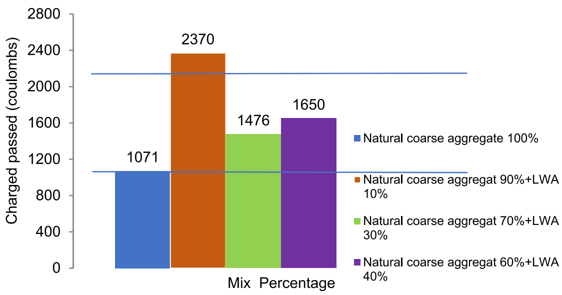


Fig. 11. Rapid Chloride permeability test (RCPT) values for LWAC mixes.

chloride ion creates expansion, cracking, and deterioration of the supporting steel in the concrete [64]. Adding of LWA into the concrete mixes reduces the chloride ion permeability (Fig. 11). The key aspects covered are: Incorporating LWA, derived from materials such as rice husk ash (RHA) and waste glass, into the concrete mix reduces chloride ion permeability. LWA contributes to the geopolymerization process, forming a dense matrix that resists the penetration of chloride ions, thereby enhancing the durability of the concrete.

4. Conclusions

Using local clay, rice husk and glass from industrial waste, a lightweight aggregate concrete has been made successfully. Lightweight aggregate (LWA) from local waste materials reduces resource depletion, environmental impact, and waste management. It offers improved thermal insulation, reduced energy consumption, and enhanced structural efficiency, promoting sustainable urban development and taller buildings.

A systematic investigation has been carried out for physical, mechanical, and other properties of the prepared concrete to understand the effectiveness of this replacement of Natural coarse aggregate (NCA) with LWA. The experimental results show-

1. Addition of 20–50 % LWA turn semi-lightweight concrete (density more than 2000 kg/m^3) to lightweight concrete (density less than 2000 kg/m^3).
2. With increasing LWA in concrete mixes water absorption increases due to increased porosity. A good quality concrete has been made having the absorption of water less than 10 % (by volume) with mixture upto 40 % of LWA with Red clay and 30 % of LWA with Savar clay into the concrete mixes.
3. Drying shrinkage of the concrete decreases significantly with increasing LWA into the concrete mixes along with considerable modulus of elasticity which point toward a good workable concrete.
4. The reducing STS was significant for the concrete containing 40 % LWA at 7 days ages and getting enhanced with growing age of the concrete at 28 days. It is noteworthy to observe that a considerable progress of STS was identified after 7–28 days for concrete mix containing 40 % LWA and similar to high strength structural lightweight concrete.
5. The lower thermal conductivity of LWAC is helpful to accomplish environmental global goals.
6. The reduced chloride ion permeability of the prepared LWAC offers enhanced durability of the structural reinforcement steel and durability of the concrete.

Data availability statement

The data provided in this study can be obtained upon request from the corresponding authors.

CRediT authorship contribution statement

Sagirul Islam: Writing – review & editing, Writing – original draft, Visualization, Validation, Supervision, Software, Resources, Project administration, Methodology, Investigation, Funding acquisition, Formal analysis, Data curation, Conceptualization. **Gulshan Ara:** Writing – review & editing, Formal analysis, Data curation. **Umme Sarmeen Akhtar:** Validation, Supervision, Project administration, Investigation, Formal analysis. **Mohammad Golam Mostafa:** Visualization, Validation, Methodology, Formal analysis. **Imdadul Haque:** Visualization, Validation, Methodology, Formal analysis. **Zunayed Mahmud Shuva:** Visualization, Methodology, Investigation, Formal analysis, Data curation. **Abdus Samad:** Writing – review & editing, Writing – original draft, Supervision, Resources, Methodology, Investigation, Formal analysis.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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