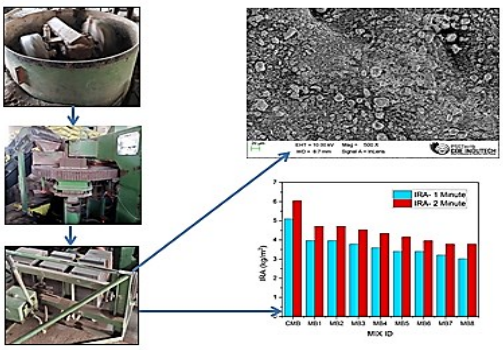
Global NEST Journal, Vol 26, No 3, 05559

Development of sustainable masonry solid blocks by the incorporation of industrial and agro waste

E. Kavitha[1], K. Mohan[2], G.E. Arunkumar and R. Udhayasakthi[4]
[1]Department of Civil Engineering, Aishwarya College of Engineering and Technology, Bhavani 638312, Tamil Nadu, India
[2]Department of Agricultural Engineering, Sri Shanmugha College of Engineering and Technology, Sankari 637304, Tamil Nadu, India
[3]Department of Civil Engineering, Shree Venkateshwara Hi- Tech Engineering College, Gobi 638455, Tamil Nadu, India
[4]Department of Civil Engineering, Nehru Institute of Technology, Coimbatore 641105, Tamil Nadu, India
Received: 19/11/2023, Accepted: 07/02/2024, Available online: 09/02/2024
*to whom all correspondence should be addressed: e-mail: kavi13suga@gmail.com
https://doi.org/10.30955/gnj.005559

Graphical abstract



Abstract

Bricks have been extensively adopted for centuries and continue to play a vital role in the construction industry. Nevertheless of its dependable workability and accessibility, fired clay brick production has been recognized for its comparatively high energy and resource requirements. Traditional clay bricks, widely used in construction for centuries, pose significant environmental challenges. The extraction of clay for brick production can result in habitat destruction and landscape alteration. The firing process in brick kilns consumes substantial amounts of energy, often derived from non-renewable sources, contributing to greenhouse gas emissions. The development of sustainable masonry solid blocks signifies a revolutionary change in the construction sector, providing a sustainable substitute for conventional building materials. These blocks, typically made from reused or locally obtained materials, demonstrate a dedication to environmental stewardship and the efficient use of resources. This innovative idea of utilizing some industrial waste such as fly ash, bagasse ash, marble dust and stone dust in solid block manufacture significantly reduces the environmental pollution problem, offers an alternative construction material source, and makes the solid blocks economical. Different types of trail mixes have been developed, and the produced masonry solid blocks underwent a series of experimental investigations. The solid bricks are being compared to conventional cement blocks. The developed sustainable solid block (MB6) exhibits a strength that is 43.78% greater than that of conventional cement solid blocks. The present study attempts to determine the optimal material proportion for innovative solid block production.

Keywords: Carbon footprint, Eco-friendly building blocks, bagasse ash, marble dust and Industrial waste

1. Introduction

Fired clay brick/block are the prime building materials used to construct homes and masonry structures from the historical period to till date. However, the endurance of time, the production methods and the usage of diverse constituent materials make the block one of the most versatile modern materials. In the production of fired clay blocks, substantial ill effects and environmental concerns are reported. With the intrinsic and potential pozzolanic characteristics, fly ash, a waste-reject from the thermal power plant, transfigured solid block production. In India, 72% of power plants are predominantly coal-fired. The abundant waste generated from the thermal stations creates environmental burdens, and the disposal is a concern. Currently, widespread research is being conducted to develop more robust and durable fly ash-based blocks and bricks using various industrial waste materials. Topical advancements in the construction industry have forced Civil Engineers to seek more efficient and long-lasting alternatives to conventional brick/block production. Several studies have taken significant steps toward manufacturing bricks using various waste materials. The utilization of debris derived from power plants into composite materials can significantly improve sustainability and address environmental waste management concerns (Mei-In Melissa and Chou 2006). Masonry bricks and blocks are the oldest and most durable building materials. The durability of masonry blocks is notable, as they exhibit a prolonged lifespan and necessitate minimal upkeep. Generally, based on raw material use, blocks are classified as clay blocks and cement blocks (Sousa *et al.* 2014; Da Silva Almeida *et al.* 2013). Fired clay blocks, also known as conventional blocks, are made of silica, alumina, lime, iron oxide, and magnesia. The constituent materials deliver high compressive strength and durability with proper drying and heating. Cement-based blocks are made from mortar, primarily cement, lime and sand. These blocks are easier to manufacture, requiring little maintenance and a large production capacity one of the primary advantages associated with cement-based blocks is their ability to grow without the requirement of heat. However, the leading ingredient, cement, required heat for its production. The production of cement leads to many environmental concerns. Numerous researchers have conducted studies on the utilization of waste materials in the production of masonry blocks. In a study conducted by Marinovic and Kostic (Marin and Kostic-Pulek 2007), the authors investigated the production of building blocks using gypsum, lime, and fly ash as raw materials. The results suggest a significant enhancement in physical strength. Similarly, the production of red-clay blocks depends on natural resources, which are in short supply worldwide. The main ingredient is clay, and its excavation from hills and lands causes serious geological problems and puts people at risk of landslides. In addition, when these traditional blocks are kiln-fired, a lot of exhaust gases are released into the air, harming the ecological system of residential areas (Raut *et al.* 2012).

There has been a notable rise in the quantity of ashes in recent years, posing a global issue in terms of their management. A considerable number of scholars are currently engaged in investigating the potential global applications of ashes. The utilization of ashes in several sectors, including agriculture, paint, ceramics, environment, and construction, is contingent upon their specific features. However, it is worth noting that a significant portion of generated ashes is currently disposed of in designated ash landfills and comparable locations (Eliche-Quesada *et al.* 2017; Mangesh *et al.* 2013). The usage of coal ash has the potential to decrease environmental impact by offering alternate solutions to the challenges associated with its disposal and by mitigating CO_2 emissions (Opiso *et al.* 2017). Previous studies have indicated that there is a global trend of rapid depletion of clay deposits as a result of ongoing soil erosion. In response to this issue, specific nations, including China, have implemented measures to reduce the utilization of clay in brick manufacturing (Abbas *et al.* 2017). The burned clay brick is widely recognized as a prevalent and abundant masonry construction material, maintaining its popularity due to its numerous distinctive features. Extensive research has been devoted to the incorporation of debris into bricks for the past century, with varying degrees of success across a wide range of waste materials (Rohan Rajput and Mayank Gupta 2016).

Rasool *et al* analysed the effects of incorporating discarded marble powder at varying amounts (0 to 15% by weight of clay). Results confirmed that the inclusion of marble powder diminished the unit weight of bricks. Results suggest that up to 12 % by weight of marble powder may be included in manufacturing burnt clay bricks to reduce the environmental waste and improve the sustainability and economic efficiency in the brick sector. Vidhya *et al*. Investigated pond ash brick's microstructural and mechanical strength properties. The authors observed that the crushing strength of bricks prepared from pond ash increased as the lime percentage increased. The density of pond ash bricks reduces as the amount of pond ash increases. Bricks had an absorption rate of less than 10 percent. The initial absorption rate and sorptivity were lower than that of conventional clay brick. Setya Winarno made concrete blocks from cement and rice husk. The maximum water absorption was 16.04 %, according to the results. The actual cost of the RH block was 42.5 % less than the total cost of conventional concrete blocks.

Gaurav Patel and Pitroda studied pond ash and Natural Sand comparatively. In accordance with the Indian standard code, it was determined that natural sand might be partially or totally substituted with pond ash in cement concrete for the production of solid blocks. Zhang *et al*. made brick with municipal waste incineration ash, fly ash, sand, and clay. Bricks were cast in various sizes and mix combinations. An optimum mix ratio was found, and test outcomes exhibited that the combination of 50% of fly ash, red clay, 30%, and 20% of sand was the optimum mix combination.

Kavitha & Vidhya conducted a study to investigate the combination of diverse leftover materials from the industry into the manufacturing of masonry blocks. The researchers reached the conclusion that these blocks exhibit reduced weight and enhanced durability characteristics. Paki Turgut explored the use of powdered lime and waste glass powder in production of masonry block. Powdered lime and cement were used to create the first form of block. The alternative variant of the block was comprised of a mixture of powdered glass and cement. The study revealed that the blocks fabricated with glass powder had a significantly elevated level of compressive strength. Kim Hung Mo and Tung-Chai explored the impact of fly ash and bottom ash on brick and block manufacture. The test results revealed that the bottom ash could be used as an aggregate to reduce bricks and blocks' density and thermal conductivity. Yeprem *et al*. investigated the application of marble dust as an additional constituent in the manufacturing process of industrial bricks. The researchers observed that including marble dust as an addition led to significant improvements in the mechanical characteristics of the produced bricks.

Mangesh *et al*. performed a study on the incorporation of bagasse ash into the production of unfired bricks. of unfired bricks. The researchers reached the conclusion that the bricks also fulfil the function of managing solid waste and serve as an innovative and sustainable resource for construction. The utilization of bricks is particularly applicable in regional construction, particularly for the construction of walls that do not bear significant loads. Hence, the brick/block production using Cement and Clay makes the brick industry non-eco-friendly. Utilizing eco-friendly solid blocks offers advantages such as minimizing environmental harm, enhancing energy efficiency, and the possibility of long-term cost savings. The unique aspect of eco-friendly masonry solid blocks resides in their holistic strategy for sustainability. These blocks revolutionize the benchmarks for eco-friendly construction materials by incorporating recycled composition, energy-efficient production methods, and improved performance. The viable option is to use the various potential industrial and agricultural wastes, namely bagasse ash, fly ash, stone dust and marble dust with the change in the production method for eco-friendly brick manufacturing.

1.1. Research significance

Industrial wastes are not only an ecological problem but also an economic loss. Numerous industries generate a large amount of non-biodegradable waste, and as a result, the vast majority of this waste is disposed of directly in landfills. Nevertheless, the scarcity of naturally occurring materials like as aggregates and clay is steadily increasing as a result of the growing estimation of landfill space and a lack of environmental consciousness. Utilizing industry and agro wastes such as bagasse ash, fly ash, marble dust and stone dust to manufacture walling materials promotes sustainable and low-cost development while mitigating natural resource depletion.

2. Experimental investigation

2.1. Ingredients utilised in production of solid blocks

The ingredients utilised for the making of solid blocks are Fly Ash (FA), Bagasse Ash (BA), Marble Dust (MD), Stone Dust (SD), lime and gypsum. Fly ash of Class C type, obtained from NTPS, Neyveli, Tamil Nadu, India, is engaged in the current investigation. Gypsum, a calcium sulphate mineral, is obtained from Tuticorin, Tamil Nadu, and India. Lime is introduced into the fly ash-based products to incorporate the binding characteristics. At room temperature, fly ash reacts with lime and produces components responsible for the strength properties of the solid blocks. In the current study, the hydraulic lime powder is procured from Pollachi, Tamil Nadu, and India. Stone dust is a residual material that is generated as a result of the stone-crushing procedure and is a highly concentrated material ideal to use as aggregates in construction products, particularly fine aggregates (Shakir *et al.* 2013). Stone dust is procured from the local crusher unit. The bagasse ash obtained in this study was collected from Sakthi Sugars Limited, located in Sakthinagar, Tamil Nadu, India. It is produced during the combustion of the fibrous waste of sugarcane juice extraction. The primary elements in the ash are silica, alumina, and lime.

Leftover marble dust was procured from the local marble polishing factory. It is produced as a residue during the operations of marble cutting, honing, or polishing. The properties of all constituents are presented in Table 1. Figure1 exhibits the sample of all constituents utilized in the production of solid blocks.

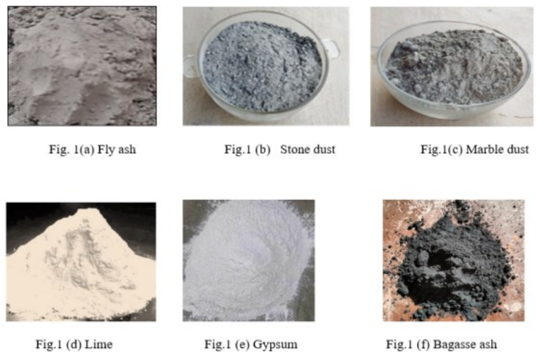


Figure 1. Sample of materials

Table 1. Properties of all ingredients

Properties	Class F Fly Ash	Bagasse Ash	Lime	Gypsum	Marble dust	Stone dust
Specific gravity	2.21	2.28	2.24	2.46	2.88	3.08
Surface area(m^2/kg)	342	297	305	325	280	284
Bulk density(kg/m^3)	1132	995	670	890	1490	1975
Composition (%)						
SiO_2	45.52	56.50	0.29	2.97	66.17	57.64
CaO	20.52	16.85	73.11	30.12	2.18	8.26
MgO	1.20	4.23	0.69	3.49	1.09	5.47
Fe_2O_3	3.56	13.20	0.31	0.82	2.85	7.98
Al_2O_3	18.47	3.42	0.43	1.18	14.16	17.79

Table 2. Mix proportions in %

MIX ID	Class C Fly Ash	Bagasse Ash	Lime	Gypsum	Stone dust	Marble dust
MB1	50	10	10	5	22.50	2.50
MB2	50	10	10	5	20.00	5.00
MB3	50	10	10	5	17.50	7.50
MB4	50	10	10	5	15.00	10.00
MB5	50	10	10	5	12.50	12.50
MB6	50	10	10	5	10.00	15.00
MB7	50	10	10	5	7.50	17.50
MB8	50	10	10	5	5.00	20.00
MB9	50	10	10	5	2.50	22.50

2.2. Manufacturing of solid blocks

Table 2 demonstrates the proportions of solid blocks with varying material compositions. The solid blocks are produced using a mould with dimensions of 230mm × 230mm × 75mm. A total of 9 mix blends were made, each consisting of varying compositions of components. The different constituents were meticulously blended in a dried state, in the suitable ratios, employing a pan mixer until a homogeneous amalgamation was attained. The addition of water was followed by prolonged mixing as part of the subsequent processing steps, after which the mixture was transferred onto a belt conveyor. A hydraulic pressure of 48 tons was exerted on the block mould, resulting in the casting of green construction blocks. These blocks were subsequently conveyed on a wooden rack and allow to cure in an open-air environment for duration of 48 hours. Subsequently, the blocks were conveyed to undergo a period of sun drying lasting an additional two days, followed by a subsequent duration of 14 days allocated for water curing. Prior to shipping, the solid blocks undergo testing. Figure 2 illustrates the manufacturing process of a solid block.

2.3. Testing of solid blocks

Comprehensive research has been conducted on solid blocks to assess their compressive strength, water absorption, and block density, initial rate of absorption, efflorescence and chemical tests. The compressive strength test was conducted at 7, 14, and 28 days, following the guidelines outlined in the BIS 2185 (Part 1): 2005. The compressive strength of a solid block is obtained by dividing the load at which failure occurs by the cross-sectional area of the solid block. The determination of block density implies the computation of the ratio between the mass and volume of the block. The durability of solid blocks is significantly influenced by the process of water absorption. The degree to which water is able to permeate into blocks is indicative of the durability of the specimens. The measurement of water absorption was carried out following 28 days in accordance with the guidelines established in BIS 2185. The test specimens were completely submerged in water at ambient temperature for a duration of 24 hours. The measurement is recorded as the weight of the sample when it is wet (W1). The specimens are subjected to an elevated temperature ranging from 100◦C to 115◦C for duration of 24 hours, after which they are weighed to determine their dry weight (W2).The efflorescence test is conducted in order to assess the quantity of soluble salts that are contained within a block. The presence of soluble salts on the block surface is indicative of efflorescence phenomena. The specimens were meticulously placed within the container containing a water depth of 25 mm. The entire setup was positioned in a well-ventilated area at room temperature, allowing the blocks to absorb the water from the container and the surplus water to evaporate.

Figure 2. Manufacturiong process of solid block

2.4. Discussion on test findings of basic properties of solid block

2.4.1. Compressive strength of masonry solid blocks

The experimental data for the compressive strength of solid blocks, produced using both waste materials and standard cement blocks, are reported in Table 3. Additionally, these results are visually depicted in Figure 3.

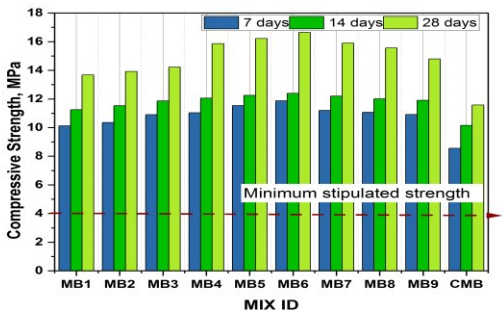


Figure 3. Compressive strength development of solid blocks

Table 3. Summary of test findings of basic properties of solid blocks

S. No	Mix ID	Compressive Strength (MPa)			Density in kg/m³	Water absorption (%)
		7 days	14 days	28 days		
1	MB1	10.12	11.25	13.68	2280	12.32
2	MB2	10.36	11.53	13.92	2264	12.05
3	MB3	10.91	11.86	14.23	2240	11.40
4	MB4	11.04	12.06	15.86	2178	11.21
5	MB5	11.54	12.25	16.22	2152	11.06
6	MB6	11.87	12.39	16.65	2126	10.74
7	MB7	11.20	12.20	15.90	2097	10.29
8	MB8	11.07	12.01	15.56	2080	10.03
9	MB9	10.92	11.90	14.80	2063	9.96
10	CMB	8.55	10.15	11.58	2315	14.02

The compressive strength of solid blocks typically falls within the range of 13.68 to 16.65 MPa. The MB6 mixture had the maximum crushing strength in comparison to the other mixtures. The strength of the CMB was measured to be 11.58 MPa. The mix ID MB6 exhibits a strength that is 43.78% greater than that of conventional cement solid blocks. By incorporating FA and BA and other substances into solid blocks, their strength can be improved as a result of the pozzolanic reactions that take place during the curing process. This process leads to the creation of a more compact and closely packed matrix within the solid block structure. According to the BIS 2185-Part 1 standard, the least compressive strength required for the solid load-bearing masonry unit of C (4.0) Grade is 4 MPa. All the sustainable solid blocks that have been designed meet the parameters outlined by the Indian standards.

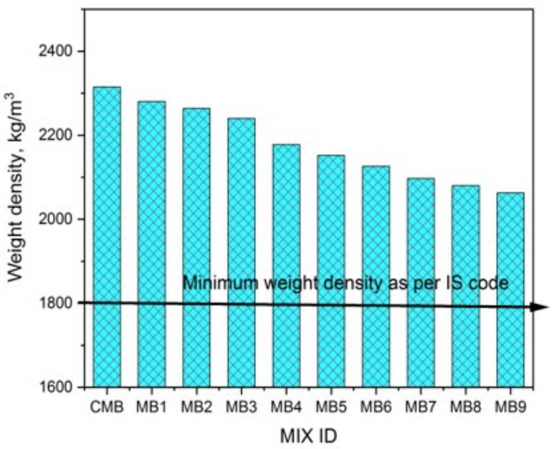


Figure 4. Density of solid blocks

2.4.2. Density of solid blocks

Three representative block samples are selected in order to ascertain the density of each mixture composition. Figure 4 depicts the density of solid blocks. The data suggests that there is a little drop in the density of the masonry solid blocks when the utilization of marble dust increases. The density values for solid block range from 2063 to 2280 kg/m^3. The inclusion of fly ash in the solid block mixture leads to a significant reduction in density compared to traditional cement blocks. By incorporating fly ash and other substances into the solid blocks, the density can be decreased as a result of their lower specific gravity and porosity (Kavitha and Vidhya 2022; Mo and Ling 2022). The overall significance of this value is lower in comparison to that of conventional cement solid blocks.

2.4.3. Water absorption test on solid blocks

Three solid block samples are examined for each mix combination to assess their water absorption property. Figure 5 illustrates the water absorption characteristics of solid blocks. The adding of marble dust to the block caused in a substantial decrease in water absorption. The range of water absorption spans from 9.96% to a maximum value of 12.32%. The solid block, identified as Mix ID MB 9, exhibits significantly lower water absorption properties, measuring 52%, in comparison to the conventional CMB. The solid blocks composed of fly ash and bagasse ash exhibit a minimal proportion of water absorption. The fine texture of FA and BA makes them good filler materials, since they effectively reduce porosity and water absorption values (Neslihan Dogan-Saglamtimur *et al.* 2021; Vidhya *et al.* 2020; Xinyu Shen *et al.* 2023).

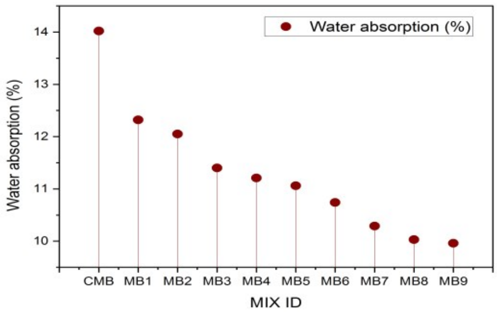


Figure 5. Water absorption of solid blocks

2.4.4. Efflorescence test

The test is performed in accordance with the method outlined in BIS 12894:2002. Based on the Physical observation, it may be inferred that there is no discernible evidence of efflorescence present on any of the solid blocks.

2.5. Durability performance on solid blocks

The solid blocks are tested for the durability performance by performing tests as Initial rate of absorption and chemical resistance tests. .

2.5.1. Initial Rate of Water Absorption (IRA)

The IRA refers to the quantity of water that is engrossed by the block within a specific time frame of one and two minutes. The evaluation is performed in adherence to the criteria specified in ASTM C67. Figure 6 illustrates the experimental setting for the IRA test. Sorptivity refers to the inherent characteristic of porous materials to absorb water through the process of capillary transmission.

Figure 6. Experimental Setup for Initial Rate of Absorption

IRA for the solid block was computed for an interval of 1-minute and 2-minute.

$$I = \frac{m}{(a \, x \, \rho)} \quad (3)$$

Where

ρ–density of the water in g/mm^3

m–Change in weight of block in grams

a–area of the bed surface of block specimen in mm^2

2.5.2. Chemical resistance tests

One set of block specimens were soaked in water with 5% magnesium sulphate. Another set of block were immersed in water with 5% sodium chloride for 90 days. The chemical resistance test is performed by submerging the solid bocks in solutions of magnesium sulphate and sodium chloride for a specified duration of exposure. The alterations in weight and the decline in compressive strength are documented at different time periods. The experimental arrangements of chemical tests are depicted in Figure 7.

2.5.3. Test findings on durability performance of solid blocks

2.5.3.1 IRA test

The study involved conducting the IRA test on different compositions of solid blocks and conventional cement blocks. The findings of the IRA test conducted at intervals of one minute and two minutes are displayed in Table 4.

Table 4. IRA values for solid blocks

Type of block	Dry weight in Kg	IRA for 1 minute			IRA for 2 minutes		
		Wet weight in kg	Δm in (kg)	IRA (kg/m²)	Wet weight in kg	Δm in (kg)	IRA (kg/m²)
MB1	8.77	8.98	0.21	3.96	9.02	0.25	4.72
MB2	8.71	8.92	0.21	3.96	8.96	0.25	4.72
MB3	8.67	8.87	0.20	3.78	8.91	0.24	4.53
MB4	8.59	8.78	0.19	3.59	8.82	0.23	4.34
MB5	8.56	8.74	0.18	3.40	8.78	0.22	4.15
MB6	8.52	8.7	0.18	3.40	8.73	0.21	3.96
MB7	8.39	8.56	0.17	3.21	8.59	0.20	3.78
MB8	8.29	8.45	0.16	3.02	8.49	0.20	3.78
MB9	7.88	8.04	0.16	3.02	8.7	0.19	3.59
CMB	9.38	9.65	0.27	5.10	9.7	0.32	6.04

Table 5. Weight of the solid block after being exposed to chemicals for varying periods

Days of Exposure	MB6		CMB	
	$MgSO_4$ Solution	NaCl Solution	$MgSO_4$ Solution	NaCl Solution
	Weight of solid blocks in kg			
7	8.60	8.57	9.43	9.40
28	8.66	8.62	9.48	9.48
56	8.72	8.68	9.69	9.62
90	8.77	8.74	9.83	9.79

Table 6. Compressive strength of the solid block after being exposed to chemicals for varying periods

Days of Exposure	MB6		CMB	
	$MgSO_4$ Solution	NaCl Solution	$MgSO_4$ Solution	NaCl Solution
	Mean compressive strength, Mpa			
7	16.58	16.60	11.50	11.54
28	16.45	16.53	11.40	11.44
56	16.27	16.46	11.27	11.30
90	16.12	16.20	11.03	11.15

Table 7. Percentage change in mass and compressive strength following a 90-day chemical exposure period

Block type	$MgSO_4$ Solution		NaCl Solution	
	Mass gain in %	Strength loss in %	Mass gain in %	Strength loss in %
MB6	2.93	3.28	2.58	2.77
CMB	4.80	4.98	3.73	3.85

Figure 7. Chemical attack tests for solid blocks

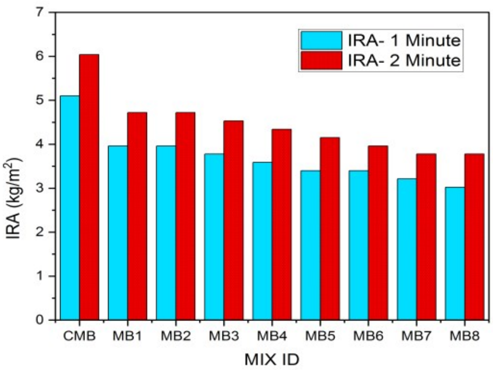


Figure 8. IRA Tests on solid blocks

Based on the data presented in Figure 8, the observed IRA value for block MB 9 is comparatively lower than that of the other mixtures. The initial rate of absorption for MB9 is 68% lower than that of typical cement solid blocks at a one-minute time interval. it is apparent that the sustainable solid blocks exhibit significantly lower levels of water absorption at both the one-minute and two-minute time intervals when compared to traditional cement solid blocks. The reduced water absorption property observed in solid blocks composed of industrial waste can be attributed to their impermeability (Jitendra and Khed 2020). The values of the IRA exert a significant impact on the bonding characteristics observed in block construction. There exists an inverse relationship among the results of the IRA and the compressive strength of the blocks. The solid block mixture with greater density and strength exhibited a lower rate of absorption.

2.5.3.2 Chemical resistance tests

When compared to traditional cement blocks, the solid block with Mix ID MB9 outperforms in mechanical characteristics, hence it is selected for chemical resistance studies. Tables 5 and 6 show the blocks' weight and compressive strength after being exposed to chemicals for varying periods.

Table 7 displays the weight loss and strength deterioration of MB6 and CMB solid blocks following a 90-day exposure period. The MB 6 mixture exhibited a reduction in weight growth of 63.8%, 44.57%, and 42.8% when exposed to Sodium Sulphate and Sodium Chloride solutions, in comparison to conventional cement blocks. The solid blocks composed of waste materials exhibited increased weight gain and decreased strength when subjected to exposure to a sodium sulphate solution. There is a clear correlation between weight growth and the decrease in compressive strength observed during chemical assault tests. Figures 9 and 10 depict the progressive development of weight and compressive strength, respectively, following exposure over different durations.

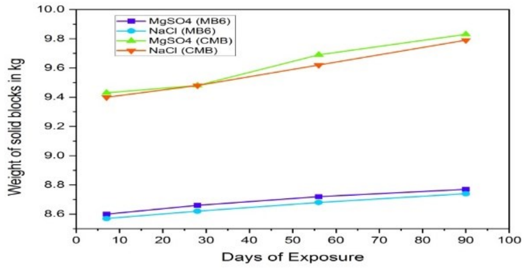


Figure 9. Weight of the block after chemical attack

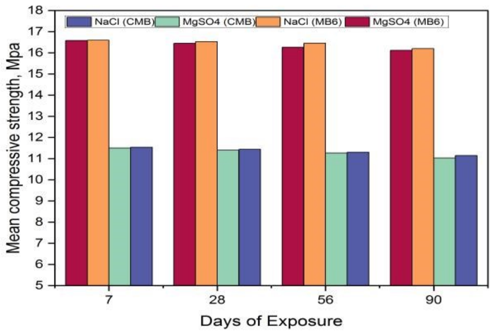


Figure 10. Compressive strength of the block after chemical attack

The strength reduction observed in sustainable solid blocks is 51.82% lower compared to conventional masonry blocks when exposed to a sodium sulphate solution. The sustainable solid block demonstrates superior performance in terms of durability, as it exhibits minimal weight growth and greater resistance to compressive strength compared to cement blocks. The high impermeability of sustainable solid masonry blocks composed of fly ash, packing ash, and marble dust is the primary reason for this phenomenon. Based on the findings derived from the chemical resistance investigation, it can be inferred that the sustainable solid blocks exhibited favorable aesthetic qualities and demonstrated notably superior performance when exposed to harsh chemical solutions. Hence, it is recommended that these blocks be utilized in challenging climatic conditions, since they are designed to exhibit prolonged lifespan and enhanced durability.

2.6. Mineralogical characterization for solid block powder

The Mineralogical Characterization of solid block powder sample (MB6) were examined through the utilization of SEM (Scanning Electron Microscopy), XRD (X-ray diffraction) techniques, and EDS (Energy Dispersive X-ray Spectroscopy).

2.6.1. SEM analysis

SEM is a technique employed to examine the topography and composition of materials. The SEM images of the sustainable solid block powder sample with 500 kx and 100 kx magnifications are depicted in Figure 11(a) and 11(b). The majority of block powder particles exhibits a spherical morphology and possesses a uniform internal composition. The particles comprising the solid block powder exhibit a fused appearance. The texture of the object exhibits a remarkably high degree of compactness. The porosity of the solid block powder's microstructure is reduced. The micrograph reveals the presence of visible sections of fly ash, with no discernible porous structure observed. The enhancement of ingredient density might be emphasized.

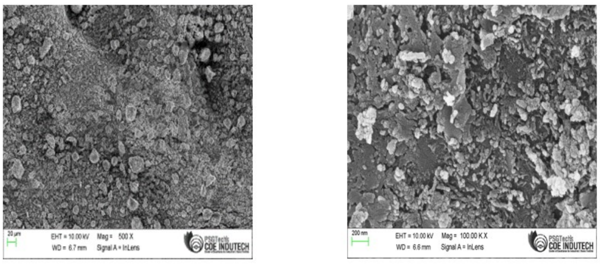


Fig. 11(a) 500 kx magnification **Fig. 11(a) 100 kx magnification**

Figure 11. SEM image of sustainable solid block powder

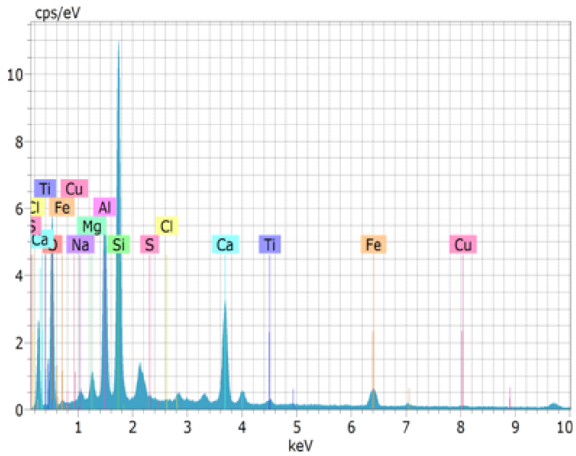


Figure 12. EDS analysis of solid block powder (MB6)

2.6.2. EDS Analysis

The technique being referred to is widely employed for the analysis of qualitative data pertaining to elemental composition. The EDS analysis of the solid block powder sample of the optimum blend (MB6) is illustrated in Figure 12. According to the data presented in Figure 12, the solid block powder comprises 35.05% silica, 18.89% alumina, 20.12% calcium, 9.52% iron oxide, and a little quantity of magnesium oxide. The presence of alumina, silica, and calcium in the composition of these solid blocks plays a significant role in determining their environmentally friendly attributes and exerting an impact on issues such as recyclability, energy efficiency, and sustainability. Additionally, the aforementioned compositions contribute to the binding properties, thermal insulation strength, and durability of solid blocks.

2.6.3. XRD Analysis

Figure 13 illustrates the XRD investigation conducted on the solid block powder. The peak observed within the angular range of 20 to 35 degrees (2Θ) exhibits a lower magnitude compared to that of fly ash. This proposition suggests that the substance exhibits lower reactivity compared to the ash. Additionally, the high intensity and narrow width of the peaks indicate a higher proportion of crystalline content in the material compared to the amorphous phases. The samples that contained limestone displayed heightened calcite peaks, which become more prominent as the limestone concentration increased. This can be attributed to the fact that limestone mostly consists of calcite, which is formed of calcium carbonate**.**

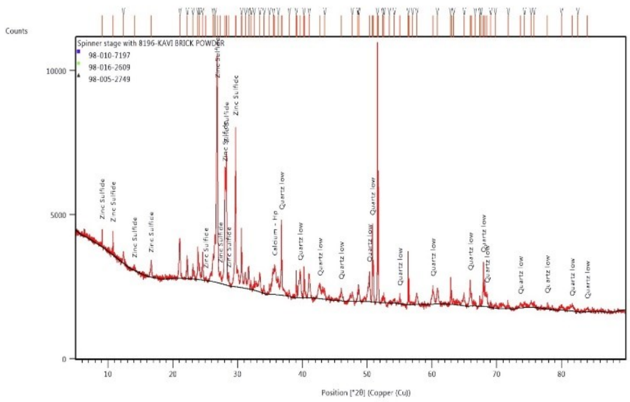


Figure 13. XRD analysis of solid block powder (MB6)

3. Conclusions

Based on the findings of the experimental study, the subsequent inferences can be derived.

- The utilization of discarded materials in the production of masonry blocks represents a contemporary approach that eliminates the conventional practices of block burning and curing. The efficient utilization of ash in the solid block production significantly mitigates environmental pollution issues associated with solid waste disposal.
- The sustainable solid block has superior performance in terms of mechanical and durability characteristics when compared to traditional cement blocks.
- According to the BIS 2185-Part 1 standard, the minimal compressive strength required for the solid load-bearing masonry unit of C (4.0) Grade is 4 MPa. All the sustainable solid blocks that have been designed meet the parameters outlined by the Indian standards. The mix ID MB6 exhibits a strength that is 43.78% greater than that of conventional cement solid blocks.
- The solid blocks composed of fly ash and bagasse ash exhibit a minimal proportion of water absorption.

- As per the specifications outlined in IS code, it is mandated that solid blocks intended for use as load-bearing units must possess a minimum density of 1800 kg/m^3. Nevertheless, all the observed outcomes of solid blocks meet the established standards.
- During the IRA tests, it is evident that the sustainable solid bloc ks demonstrate considerably reduced water absorption levels at both the one-minute and two-minute time intervals in comparison to conventional cement solid blocks. The IRA for MB9 is 68% lower than that of typical cement solid blocks at a one-minute time interval.
- The sustainable solid blocks exhibited notable resistance to chemical degradation during different durations of exposure to various chemicals.
- Based on microstructural investigations, it was determined that the inclusion of alumina, calcium, and silica, in the composition of these solid blocks plays a significant role in enhancing their binding characteristics, thermal insulation capabilities, and overall durability.
- Therefore, the implementation of sustainable solid block manufacturing appears to be a rational approach that enables the preservation of natural resources, reduction of pollution, and conservation of the environment, thereby advancing the adoption of greener technologies.

Conflicts of Interest

There are no conflicting interests stated by the authors.

Acknowledgment

No organization supported the authors' work submission

ORCID ID

0000-0002-8937-0125

References

Abbas S., Saleem M.A., Kazmi S.M.S. and Munir M.J. (2017). Production of sustainable clay bricks using waste fly ash: Mechanical and durability properties, *Journal of Building Engineering*., **14**, 7–14.

Ali Murtaza Rasool., Hameed A., Qureshi M.U., Ibrahim Y.E., AsadUllahQazi. and Ali Sumair A. (2021). Experimental study on strength and endurance performance of burnt clay bricks incorporating marble waste, *Journal of Asian Architecture and Building Engineering*, DOI: 10.1080/ 13467581.2021.2024203

ASTM C67. Testing of Brick and Structural Clay Tile, American Society for Testing and Materials', Philadelphia, PA, USA

Bilgin N., Yeprem H.A., Arslan S., Bilgin A., Gunay E. and Marsoglu M. (2012). Use of waste marble powder in brick industry, *Construction Building Materials*, **29**, 449–457.

BIS 2185 Part–1. (2005). Concrete Masonry Units –Specification Part 1 Hollow and Solid Concrete Blocks, Bureau of Indian Standards, New Delhi, India.

BIS12894. (2002). Pulverized Fuel Ash-Lime Bricks–Specification, Bureau of Indian Standards, New Delhi, India.

Da Silva Almeida G., Da Silva J.B., Silva C.J., Swarnakar R., De Araújo Neves G. and DeLima A.G. (2013). Heat and mass transport in an industrial tunnel dryer: modeling and simulation applied to hollow bricks, *Applied Thermal Engineering*. **55**, 78–86.

Dogan- Saglamtimur N., Bilgil A., Szechyńska-Hebda M. and SławomirParzych MarekHebda. (2021). Eco-Friendly Fired Brick Produced from Industrial Ash and Natural Clay: A Study of Waste Reuse', *Materials*, **14**(4), 877, https://doi.org/10.3390/ma14040877

Eliche-Quesada D., Felipe-Sesé M.A., Moreno-Molina A.J., Franco F. and Infantes-Molina A. (2017). Investigation of using bottom or fly pine-olive pruning ash to produce environmental friendly ceramic materials, *Applied Clay Science*., **135**, 333–346.

Gaurav Kantilal Patel. and Jayeshkumarpitroda. (2013). Assessment of natural sand and pond ash in Indian context, *International Journal of Engineering Trends and Technology,* **4(10)**, 4287–4291.

Haiying Z., ZhaoYoucai. and Jingyu Q. (2011). Utilization of municipal solid waste incineration (MSWI) fly ash in ceramic brick product characterization and environmental toxicity, *Waste Management*, **31(2)**, 331–341.

Jitendra K. and Veerendrakumar C. Khed. (**2020)**. Optimization of concrete blocks with high volume fly ash and foundry sand. *Materials Today: Proceedings*, **27(2),** 1172–1179.

Kavitha E. and Vidhya K. (2022). Strength and durability studies on sustainable eco-friendly green solid blocks, *International Journal of Coal Preparation and Utilization*, **42**(9), 2551–2565.

Kim Hung Mo. and Tung-Chai Ling. (2022). Utilization of coal fly ash and bottom ash in brick and block products, Low Carbon Stabilization and Solidification of Hazardous Wastes, *Elsevier, Weng*, 355–371.

Madurwar M.V., Mandavgane S.A. and Ralegaonkar R.V. (2014). Use of sugarcane bagasse ash as brick material, *Current Science*, **17 (6)**, 1044–1051.

Mangesh V. Madurwar, Rahul V. Ralegaonkar, Sachin A. Mandavgane, (2013). Application of agro-waste for sustainable construction materials: A review, *Construction and Building Materials*, **38**, 872–878.

Marin S. and Kostic-Pulek A. (2007). Examination of the system fly ash-lime - calcined gypsum - water, *Journal of Physics and Chemistry of Solids*, **68**, 1121–1125

Mei-In Melissa. and Chou P.I. (2006). Manufacturing fired bricks with class f fly ash from Illinois basin coals, Combustion By products Recycling Consortium Ash lines**, 7(3)**, 1–8.

Opiso E.M., Sato T. and Otake T. (2017). Microstructural properties of hardened cement paste blended with coal fly ash, sugar mill lime sludge and rice hull ash, *Advanced Concrete Construction*., **5(3)**, 289–301.

Raut S.P., Sedmake R., Sunil Dhunde R.V. Ralegaonkar. and Mandavgane S.A. (2012). Reuse of recycle paper mill waste in energy absorbing light weight bricks, *Construction and Building Materials*, **27 (1**), 247–251,

Rohan Rajput R. and Gupta M. (2016). Utilization of Bagasse Ash as A Brick Material, A Review, *International Research Journal of Engineering and Technology*, **3(8)**, 1893–1896.

SetyaWinarno. (2019). Comparative Strength and Cost of Rice Husk Concrete Block, MATEC Web of Conferences, 280, 1–10, DOI: 10.1051/matecconf/201928004002

Shakir A.A., Naganathan S. and Mustapha K.N. (2013). Properties of bricks made using fly ash, quarry dust, and billet scale, *Construction and Building Materials*, **41**, 131–138.

Shen X., Luo W., Ren P. and Wan Z. (2023). Performance of sustainable ternary blended cement containing municipal solid waste incineration fly ash coupled with slag, coal fly ash or metakaolin, *Journal of Building Engineering*, **82**, 108301, https://doi.org/10.1016/j.jobe.2023.108301.

Sousa L.C., Sousa H., Castro C.F., António C. C. and Sousa R. (2014). A new light weight masonry block: thermal and mechanical performance, *Archives of Civil and Mechanical Engineering*, **14(1)**, 160–169.

Turgut P. (2005). Lime stone dust and glass powder as new brick material, Materials and Sciences, **41**, 805–813.

Vidhya K. and Kandasamy S. (2013). Study on properties of bricks manufactured using fly ash and pond ash, International *Journal of Pollution Research*, **32(2)**, 405–409.

Vidhya K. and Shivasakthivadivelan R.A. and Kavitha E. and Revathi S. (2020). Experimental Study on Greener Brick Using Sustainable Materials, Emperor *Journal of Applied Scientific Research*, **2(8)**, 1–9.