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Experimental Study on Mechanical and Durability Behaviour of a Sustainable Masonry Block Incorporating Agricultural and Industrial Wastes

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Abstract

Objectives: The production of conventional cement blocks consumes significant amount of cement. The production of cement, involves significant energy consumption and releases carbon dioxide emissions, contributing to carbon footprint. However, advancements in sustainable masonry block production have been made to minimize these drawbacks. Hence, this research aims to develop a sustainable masonry solid block by incorporating Rice Husk Ash (RHA) and Flay Ash (FA). **Methods:** The manuscript discusses the mechanical and durability properties of sustainable masonry block and comparing the result with the conventional cement blocks. The materials used are FA, Lime, Gypsum, RHA, Marble Dust Powder (MDP), Stone Quarry Dust (SQD). The solid blocks tested for Compressive strength, Density, Water absorption, Initial rate of water absorption, efflorescence, and chemical resistance. **Findings:** The results showed that, the addition of RHA, FA, and MDP enhanced the compressive strength of the solid blocks upto 46% when compared to convention cement block. A density reduction of 2.5% was achieved. It also exhibited a reduction in water absorption of 29.2%. IRA tests evident that the sustainable solid blocks shows reduced water absorption levels at both the one-minute and two-minute time intervals in comparison to conventional cement solid blocks. At a one-minute time, the rate of absorption for M4 is 69% lower when compared to conventional cement solid blocks. The RHA, FA and MDP admixed blocks showed better durability properties in terms of efflorescence, and chemical resistance. **Novelty :** This solid block production method is an innovative methodology that supports the conservation of natural resources, reduces pollution, and preserves the environment. As a result, it encourages the advancement of eco-friendly technology.

Keywords: Sustainable building blocks; Fly ash; Lime; Rice husk ash; Marble dust; Stone quarry dust

1 Introduction

Fired clay bricks have been the primary construction materials for dwellings and masonry constructions since ancient times up till the present day. Nevertheless, the block's durability, manufacturing techniques, and utilization of various components contribute to its status as one of the most adaptable contemporary materials. Significant adverse consequences and environmental problems have been identified in the manufacturing process of burnt clay bricks. The cement-sand block also is a frequently employed material for constructing masonry walls in residential units. Cement sand blocks typically consist of around 10 to 20% cement and 80 to 90% river sand or natural sand. Cement sand blocks include advantages such as superior durability, the ability to be produced locally, visually appealing aesthetics even without surface treatment, remarkable resistance to fire and floods, and minimal maintenance needs. However, the creation of cement-sand blocks is not eco-friendly due to the adverse environmental implications resulting from cement production and river sand excavation. In recent years, there has been a significant emphasis on the utilization of supplemental cementing materials (SCMs) as partial or complete replacements for cement. Fly ash, a waste byproduct from thermal power plants, has transformed the manufacture of solid blocks because to its inherent and prospective pozzolanic properties. The copious waste produced by thermal power plants poses significant environmental challenges, and its proper disposal is a pressing issue. Presently, extensive research is underway to create eco-friendly blocks and bricks made from fly ash and industrial waste materials. Several studies have made substantial progress in the production of bricks utilizing different waste sources. Integrating power plant waste into composite materials can greatly enhance sustainability and tackle environmental waste management issues [1]. Masonry bricks and blocks are the most ancient and long-lasting construction materials. Masonry blocks are highly durable, with a long lifespan and requiring low maintenance. Blocks are typically categorized as clay blocks and cement blocks, based on the type of raw material used. [2,3]

Conventional blocks, often referred to as fired clay blocks, are composed of silica, alumina, lime, iron oxide, and magnesia. The constituent materials exhibit good compressive strength and durability when subjected to appropriate drying and heating processes. Cement blocks are produced using a mixture of mortar, predominantly consisting of cement, lime, and sand. These blocks are more readily manufacturable, necessitating not much maintenance and possessing a substantial production capacity. One of the main benefits of cement-based blocks is their capacity to expand without the need for heat. Nevertheless, the primary component, cement, necessitated the application of heat during its manufacturing process. The manufacture of cement gives rise to numerous environmental issues. Several scholars have undertaken experiments on the use of waste materials in manufacturing masonry blocks. Kumar et al. [4] investigated the use of fly ash (FA), rice husk ash (RHA), and marble dust (MDP) in geopolymer bricks and obtained the compressive strength in the range of 12.4 MPa to 18.2 MPa. Likewise, the manufacturing of red-clay blocks relies on limited natural resources that are scarce globally. Clay is the primary component, and its extraction from hills and fields leads to significant geological issues and exposes people to the danger of landslides. Furthermore, the kiln-firing process of these conventional bricks emits a significant amount of exhaust gasses, which detrimentally affects the ecological balance of residential areas [5].

The rapid growth of ashes has experienced a substantial surge in recent years, posing a worldwide issue in terms of their disposal. Numerous experts are currently engaged in the active investigation of potential global applications for ashes. The application of ashes in various industries, such as agriculture, paint, ceramics, environment, and building, depends on their distinctive characteristics[6]. Nevertheless, it is important to acknowledge that a substantial proportion of produced ashes is presently deposited in specifically designated ash landfills and similar sites[7,8]. The utilization of coal ash has the capacity to reduce environmental effect by providing alternative approaches to the difficulties related to its disposal and by mitigating CO_2 emissions[9]. Researches has demonstrated a worldwide pattern of fast reduction in clay deposits due to continuous soil erosion. As a response to this problem, certain countries, such as China, have taken steps to decrease the use of clay in the production of bricks[10]. The fired clay brick is widely acknowledged as a prominent and abundant material for masonry construction, retaining its popularity due to its numerous particular characteristics. Considerable research efforts have been dedicated to integrating waste materials into bricks during the past century, yielding variable levels of success with a diverse waste material[11].

Rasool et al.[12] examined the impact of adding different quantities (ranging from 0 to 15% by weight of clay) of waste marble powder. The results verified that the use of marble powder reduced the density of bricks. The findings indicate that including marble powder in the production of burnt clay bricks, up to a maximum of 12% by weight, can effectively decrease environmental waste and enhance sustainability and economic efficiency in the brick industry. Nayak et al.[13] examined the beneficial effect of fly ash in the production of bricks. Setya Winarno[14] manufactured concrete blocks using a mixture of cement and rice husk. The results indicated that the maximal water absorption reached a value of 16.04%. The RH block's cost was 42.5% lower than the overall cost of standard concrete blocks.

Tam et al.[15] conducted a comparative study on pond ash and natural sand. Based on the Indian standard code, it was concluded that pond ash can be used as a partial or complete replacement for natural sand in cement concrete to manufacture solid blocks. Yaseen et al.[16] developed silty clay-based geopolymer bricks with lesser energy input, i.e., forming pressure of 7 MPa with curing at ambient temperature.

Kavitha and Vidhya[17] did a study to examine the utilization of various residual materials from the industry in the production of masonry blocks. The researchers concluded that these blocks demonstrate decreased weight and improved durability properties. Uysal et al.[18] investigated the effect of waste marble powder, brick powder, ceramic powder, glass powder, and rice husk ash as eco-friendly aggregate in sustainable red mud-metakaolin based geopolymer composites. As a result, substitute materials have shown a successful performance, creating significant potential in the production of a sustainable geopolymer. Kim Hung Mo and Tung-Chai[19] investigated the influence of fly ash and bottom ash on the production of bricks and blocks. The test findings indicated that the bottom ash has the potential to serve as an aggregate, effectively reducing the density and thermal conductivity of bricks and blocks. The study conducted by Abbas et al.[20] examined the use of marble dust as an extra component in the production of industrial bricks. The researchers observed that the inclusion of marble dust as an addition led to significant improvements in the mechanical qualities of the produced bricks.

In their research, Mahdi et al.[21] investigated the utilization of rice husk ash in the manufacturing process of unfired bricks. According to the experts, the bricks not only fulfill their original function, but also efficiently handle solid waste and offer a unique and eco-friendly 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. The viable option is to use the various potential industrial and agricultural wastes, namely rice husk ash, fly ash, lime, gypsum, stone quarry dust and marble powder with the change in the production method for eco-friendly brick manufacturing. Though the plenty of literature available for the manufacturing of eco-friendly masonry bricks/blocks, there is no standard literatures available for the sustainable block production by using husk ash, fly ash, lime, gypsum, stone quarry dust and marble powder. Hence, this research aims to develop a sustainable masonry solid block by incorporating Rice Husk Ash (RHA) and Flay Ash (FA).

2 Methodology

2.1 Materials

The materials used for producing solid blocks are Fly Ash (FA), Rice husk ash (RHA), Marble powder (MDP), Stone quarry dust (SQD), lime, and gypsum. Fly ash was obtained from Mettur Thermal power plant, India. Gypsum was obtained from Udhaya Chemical, Pallikaranai, Chennai. RHA was procured from RR enterprises, Perambur, Chennai. MDP was obtained from local marble grinding yard. Lime is added to fly ash-based blocks to integrate the binding properties. At room temperature, the combination of fly ash and lime results in the formation of constituents that contribute to the structural integrity of the solid building blocks. For this study, the hydraulic lime powder is used. SQD is a byproduct of the stone-crushing process and is a highly concentrated substance that is well-suited for usage as aggregates in construction goods, especially as fine aggregates[22]. SQD is procured from the local crusher unit. RHA is the result of burning rice husk. Most of the volatile constituents of rice husk gradually dissipate after combustion, leaving behind mostly silicates as the main remaining residues. The RHA was obtained from the local supplier. Marble powder is generated as a byproduct when marble is cut, honed, or polished.

Marble powder was procured from the local marble polishing factory. The physical properties of all materials used are shown in Table 1 and the chemical composition are shown in Table 2. Figure 1 shows the materials used in this study. Particle size plays an important role in mechanical properties of solid blocks [23–25]. Figure 2 shows the gradation curve of fly ash and stone dust used in this study.

Fig 1. Materials used for producing solid blocks

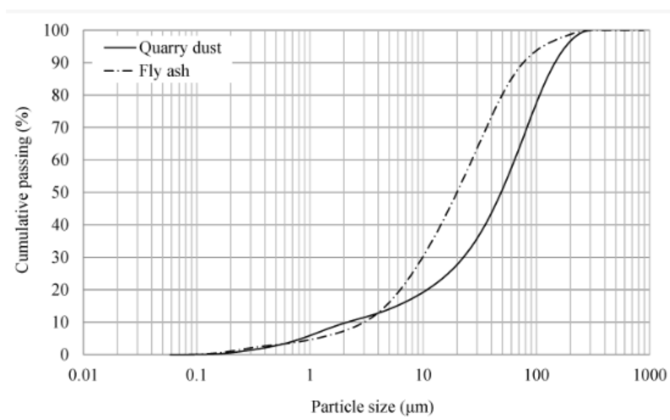

Fig 2. Gradation curve of Quarry dust and Fly ash

Table 1. Physical properties of all ingredients

S.No	Parameter	FA	RHA	Lime	Gypsum	MDP	SQD
1	Specific gravity	2.22	2.27	2.25	2.45	2.89	3.01
2	Surface area (m^2/kg)	345	299	306	324	283	275
3	Bulk density (kg/m^3)	1130	998	672	892	1495	1980

Table 2. Chemical composition of all ingredients

Parameter	CaO	SiO_2 (%)	Al_2O_3 (%)	Fe_2O_3 (%)	SO_3 (%)	MgO (%)	Na_2O (%)	K_2O (%)	TiO_2 (%)	P_2O_5 (%)	Mn_2O_3 (%)	LOI (%)	Crystal Water
Lime	91.9	3.75	2.09	0.5	0.05	1.19	0.43	-	-	-	-	-	-
Fly ash	6.1	50.9	17.9	9.8	1.0	7.2	3.8	1.9	0.8	0.2	<0.1	0.2	-

Continued on next page

Table 2 continued

Gypsum	32.8	0.63	0.14	0.38	45.72	-	-	-	-	-	-	1.16	17.18
SQD	3.81	66.76	19.2	3.62	-	1.64	1.27	2.16	-	-	-	-	-
MDP	55.6	0.6	0.4	0.2	0.1	0.1	0.36	-	0.01	0.03	-	43.2	-

2.1.1 ***Solid Blocks production***

Table 3 illustrates the ratios of solid blocks with different material compositions.

Table 3. Mix proportions

MIX ID	FA (kg/m^3)	RHA (kg/m^3)	Lime (kg/m^3)	Gypsum (kg/m^3)	SQD (kg/m^3)	MDP (kg/m^3)	Water (kg/m^3)
M1	818	307	307	102	409	102	310
M2	818	307	307	102	307	204	310
M3	818	307	307	102	204	307	310
M4	818	307	307	102	102	409	310

The solid blocks are manufactured using a mould with dimensions of 200mm x 200mm x 75mm. Four different mix blends were created in total. The various components were mixed in a dried state, using a pan mixer, in the appropriate proportions, until a uniform mixture was achieved. After the addition of water, the mixture underwent extended agitation as a part of the subsequent processing procedures, and was subsequently transported onto a belt conveyor. The block mould was subjected to a hydraulic pressure of 48 tons, which led to the production of green construction blocks. These blocks were then transported on a wooden rack and left to dry in an outdoor setting for a period of 48 hours. Afterwards, the blocks were transported to endure a two-day period of sun drying, followed by a following 14-day for water curing. Before being transporting, the solid blocks undergo testing. Figure 3 depicts the production procedure of a compacted block.

Fig 3. Manufacturing process of solid block

2.1.2 ***Testing of solid blocks***

A thorough investigation has been carried out on solid blocks to evaluate their compressive strength, water absorption, density, initial rate of absorption, efflorescence, and chemical properties. The compressive strength tests were performed at 7, 14, and 28 days, in accordance with the parameters specified in the Indian Standard (IS) 2185 (Part 1): 2005 [26]. A 2000 kN capacity compression testing system was used for this purpose and the tests were conducted at a loading rate of 2.3 kN/s (Make: AIMIL). The water absorption measurement was conducted after a period of 28 days, following the standards specified in IS 2185 [26]. To evaluate the concentration of soluble salts present in a block, efflorescence test is performed.

3 Results and Discussion

3.1 Compressive strength

The evaluation of compressive strength is essential in assessing the appropriateness of load-bearing stones for construction purposes. Blocks are primarily utilized for the construction of load-bearing masonry walls, columns, and footings. These load-bearing stone constructions mostly experience compression loads. Navaratnarajah Sathiparan et al. [27] produced sustainable blocks by using fly ash and quarry waste and tested for its compressive strength. He found that the 20% fly ash replacement yielded the highest compressive strength. The compressive strength of various mixture is shown in Figure 4. It is found that, the compressive strength of solid blocks ranges from 14.02 to 16.85 MPa. The M3 mixture exhibited superior crushing strength compared to the other mixtures. This may be attributed due to the dense mix formation for the proportion of SQD and MDP. The compressive strength of the traditional cement block (CB) was determined to be 11.52 MPa. The mix M3 demonstrates a strength that outperforms CB by 46.3%. As per the BIS 2185-Part 1 standard, the minimum compressive strength needed 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.

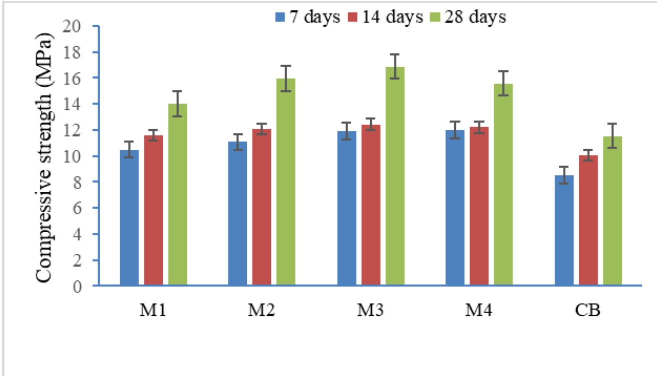

Fig 4. Compressive strength development of solid blocks

3.2 Density

Density of solid block is a vital consideration in determining the load-bearing capacity of a building or structure. Researchers[27] found that the density range varies from 2118 kg/m^3 to 2254 kg/m^3 in solid block produced with quarry waste and fly ash. He found a density reduction of upto 2.5% for fly ash substitution. In this study, three representative block samples are chosen to determine the weight density of each combination. Figure 5 illustrates the density of solid blocks. The results indicate a slight decrease in the density of the masonry solid blocks as the utilization of marble dust powder increases. The weight density values for solid blocks range from 2078 to 2267 kg/m^3. The overall significance of this value is lower in comparison to that of conventional cement solid blocks. The lower density of sustainable blocks is the advantageous because, it reduced the dead load to the structural member which bear the wall. However, all the mix satisfies the codal provision, that is, well above the minimum density requirements.

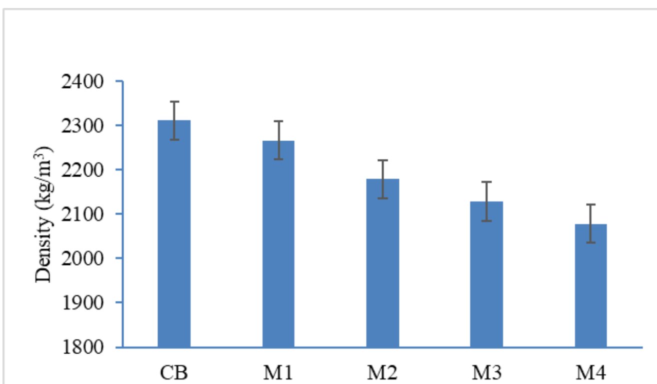

Fig 5. Density of Solid Blocks

3.3 Water absorption

The water absorption test is one of the important parameters for any construction materials. Water absorption is related to surface porosity as well as structural pores[28]. This property can affect the quality of the brick/block itself and the bond strength between the brick/block and mortar in masonry structures and can result in reducing its strength properties. Sathiparan et al.[27] found that the water absorption of sustainable blocks with fly ash and quarry water. It was revealed that the quarry sand increased the water absorption, whereas the fly ash substitution does not affect the water absorption. Three block samples of each mix combination are analyzed to evaluate their water absorption characteristic. Figure 6 depicts the water absorption properties of solid blocks. The incorporation of marble dust powder into the block resulted in a significant reduction in water absorption. The water absorption varies from 10.06% to a maximum of 12.00%. The solid block, designated as Mix ID M4, demonstrates a significantly decreased water absorption capacity, 29.2% lower, as compared to the CB. The sustainable blocks consisting of FA and RHA demonstrate a low level of water absorption. FA and RHA provide a fine texture that renders them suitable as filler materials, as they efficiently diminish porosity and water absorption levels.

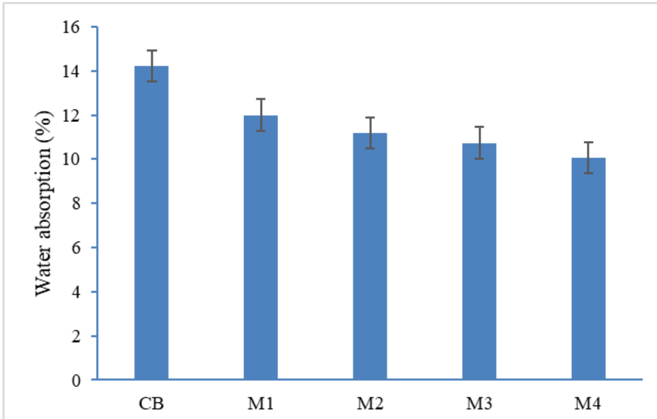

Fig 6. Water absorption of solid blocks

3.4 Efflorescence test

The test is conducted using the procedure specified in BIS 12894:2002 [24]. From the physical observation, it may be concluded that there is no visible sign of efflorescence on any of the solid blocks.

3.5 Initial rate of Water Absorption

The study involved conducting the Initial Rate of Absorption (IRA) test on different compositions of solid blocks and conventional cement blocks.

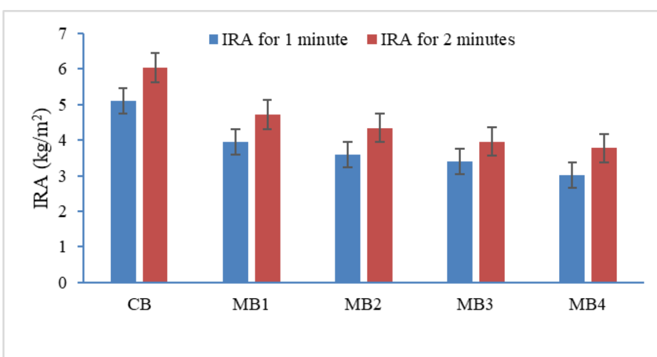

Fig 7. Initial rate of absorption

According to the results shown in Figure 7, the IRA value for block M4 is somewhat lower compared to the other combinations. At a one-minute time, the rate of absorption for M4 is 69% lower compared to conventional cement solid blocks. The sustainable solid blocks demonstrate noticeably reduced water absorption levels at both the one-minute and two-minute time intervals in comparison to conventional cement solid blocks. The impermeability of solid blocks made from industrial waste is responsible for their lower water absorption characteristic. The IRA values have a substantial influence on the bonding qualities found in block formation. An inverse correlation occurs between the outcomes of the IRA and the compressive strength of the blocks. The solid block mixture with higher density and strength demonstrated a reduced absorption rate.

3.6 Chemical resistance

When compared to traditional cement blocks, the solid block with Mix ID M3 outperforms in mechanical characteristics, hence it is selected for chemical resistance studies. Figures 9 and 10 show the blocks' weight and compressive strength after being exposed to chemicals for varying periods.

The solid block with Mix ID M3 has superior mechanical qualities when compared to ordinary cement blocks, making it the ideal choice for conducting chemical resistance investigations. Figures 8 and 9 display the weight and compressive strength of the blocks after being subjected to chemicals for different duration. Figure 9 illustrates the weight loss and strength reduction of M3 and CB solid blocks after being exposed for a period of 90 days. The M3 combination demonstrated a reduction in weight growth by 64%, 45%, and 43% when subjected to Sodium Sulphate and Sodium Chloride solutions, as compared to normal 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 attack tests. It shows the progressive development of weight and compressive strength, respectively, following exposure over different duration.

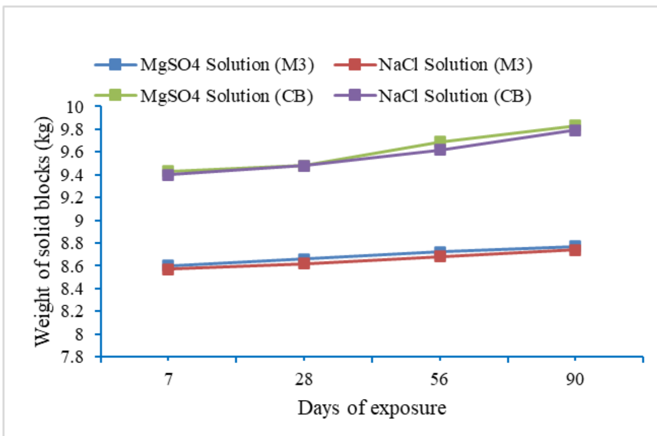

Fig 8. W eight of the block after chemical attack

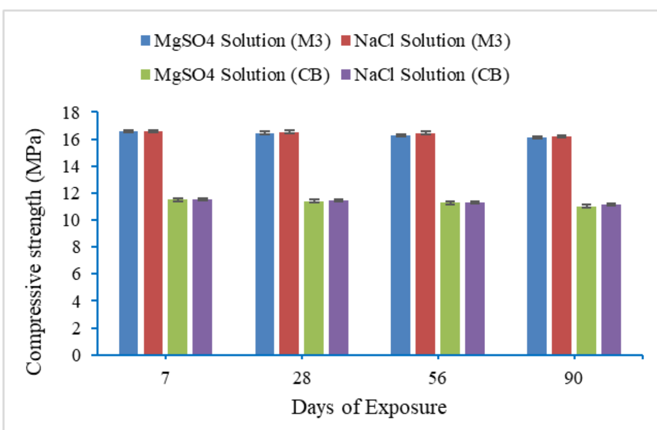

Fig 9. Compressive strength of the block after chemical attack

The sustainable solid blocks exhibit a 52% decrease in strength compared to traditional masonry blocks when subjected 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 powder 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.

3.7 SEM analysis

The Figure 10 **(a)** and **(b)** illustrates the SEM images of the sustainable solid block powder sample at magnifications of 500 kx and 100 kx respectively. Most of the particles in block powder have a spherical shape and a consistent internal composition. The particles constituting the solid block powder display a fused appearance. The object possesses a high level of density in its texture. The microstructure of the solid block powder exhibits decreased porosity. This may be attributed to the presence of CaOH gel formation from the fly ash. The micrograph demonstrates the existence of visible segments of fly ash, without any identifiable porous structure observed. The increase in ingredient density could be emphasized.

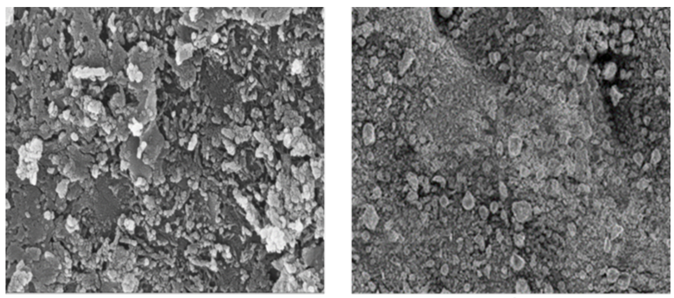

Fig 10. SEM image solid block powder at (a) 200kx magnification (Scale: 200 nm) and (b) 500x magnification (Scale: 20μm)

4 Conclusion

The manufacturing process of traditional cement blocks necessitates a significant amount of cement, rendering it environmentally unfriendly. Therefore, this study aims to create an environmentally-friendly masonry block by integrating agricultural and industrial by-products. Based on the findings of the experimental study, the subsequent inferences can be derived.

- The process of making masonry blocks from waste materials is a modern method that does away with the traditional methods of curing and burning blocks. The effective use of ash in the creation of solid blocks greatly reduces the environmental pollution problems related to the disposal of solid waste.
- The sustainable solid block has exhibited better performance in terms of mechanical and durability characteristics when compared to traditional cement blocks. The block M3 showed about 46 % increase in compressive strength when compared to conventional cement blocks. Also, the incorporation of agricultural and industrial waste reduced the density, water absorption, initial absorption rate. Efflorescence is not reported in the sustainable 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 solid blocks composed of fly ash and rice husk ash exhibit a minimal proportion of water absorption. The block M4 exhibited about 29.2 % reduction of water absorption than that of conventional cement blocks.
- In accordance with the IS code, solid blocks that are to be used as load-bearing units are required to have a weight density of at least 1800 kg/m^3. In this study, all the solid block result that has been seen fits the required standards.
- IRA tests evident that the sustainable solid blocks shows reduced water absorption levels at both the one-minute and two-minute time intervals in comparison to conventional cement solid blocks. At a one-minute time, the rate of absorption for M4 is 69% lower when compared to conventional cement solid blocks.

- The chemical resistance study demonstrate that the M3 combination demonstrated a reduction in weight growth by 64%, 45%, and 43% when subjected to Sodium Sulphate and Sodium Chloride solutions, as compared to normal cement blocks.
- The sustainable solid blocks exhibited significant resistance to chemical degradation during different duration of exposure to various chemicals.
- From the SEM analysis result, it could be found that high degree of compactness the texture of the object exhibits a remarkably. The porosity of the solid block powder's microstructure is reduced.

The implementation of sustainable solid block production using fly ash, lime, quarry dust, and marble dust powder is an innovative method that supports the conservation of natural resources, reduces pollution, and preserves the environment. This technique contributes to the advancement of eco-friendly technology.

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