Grenze International Journal of Engineering and Technology, June Issue

Development of Building Bricks using Cupola Slag and Sugarcane Bagasse Ash

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***Abstract*—Rapid urbanization and growth in construction activities have resulted in increased demand for sustainable, eco-friendly building materials. This research investigates the potential of cupola slag, a byproduct of cast iron production, and the use of sugarcane bagasse ash, a byproduct of the sugar industry, as supplementary basic materials in brick manufacturing. A constant 10% cement content was maintained in all the mixes, while the proportions of cupola slag and sugarcane bagasse ash changed from 55% to 65%. From among the three different mix designs, the M1 mix (55% cupola slag, 35% sugarcane bagasse ash and 10% cement) performed best with a compressive strength of 3.32 N/mm², which is higher than that of conventional burnt clay bricks (3.5 N/mm²). Apart from its superior strength, the M1 mix recorded the lowest water absorption of 7.0% and a density of 1529.77 kg/m³, which is within the limits suitable for structural applications. The study shall be useful to demonstrate that agricultural and industrial waste materials can be used to enhance the strength and durability of bricks to meet some of the major environmental issues facing the country. This strategy significantly helps to promote waste management and sustainability goals by reducing the dependence on natural resources and the quantity of waste disposed of in landfills. The outcome of this study shows that combining these components offers a useful and low-cost method of producing durable bricks. These eco-friendly bricks provide a sustainable solution to the infrastructure needs of smart cities apart from resonating with the concepts of green building. This would encourage more urban development projects working to reduce environmental footprints by meeting the demands of modern, sustainable cities with efficient use of resources and innovative use of waste. Cutting-edge advances in construction materials go a long way toward helping achieve the development of a circular economy and the objective of resilient, sustainable urban environments.**

***Index Terms* — Sustainable building materials, Cupola slag (CS),Sugarcane bagasse ash (SBA), Compressive strength, Eco Friendly, Industrial Waste, Density.**

I. INTRODUCTION

Rapid urbanization and industrialization have caused a tremendous increase in the generation of solid waste such that appropriate disposal is considered the most essential global concern. Inadequate land-filling in huge quantities and indiscriminate dumping of solid waste cause severe environmental harm, including groundwater pollution through leachate and soil erosion with adverse effects on public health [1]. Utilizing solid waste as a resource has become a viable solution as the need for sustainable development becomes more pressing.

Grenze ID: 01.GIJET.11.2.235_20

In addition to addressing environmental problems, recycling such waste for the creation of building materials lowers disposal costs and encourages sustainable building practices [2]. Bricks are one of the most basic building materials and are well known for their strength, durability, and affordability. However, the urbanization and rapid increase in populations have caused a divergent difference in the demand and availability of the product. Therefore, researchers, business experts, and experts are probing into environmentally friendly alternatives that are technically correct, economically viable, and must balance the environmental variables. Accordingly, there has also been an increased and significant demand for lightweight, inexpensive, and friendly materials in the construction industry [3]. India produces approximately 960 million tons of solid waste every year because of mining, industries, and agriculture. It is therefore one of the most significant waste producers in the world [4]. CS is produced during the separation of steel from its impurities in molten form in cupola furnaces. A huge amount of waste is generated through this process.

Slag contributes up to 57% of raw material inputs [5]. The industrial by-products such as cupola slag and agricultural residues such as sugarcane bagasse ash are those which have good potential for reuse in construction. With the help of such wastes, researchers aim at two significant issues: efficient waste management and the production of sustainable building materials through bricks. Although cupola slag has been explored as a partial replacement for cement and aggregates in concrete, no information is available on its use in the manufacture of bricks. On the other hand, sugarcane bagasse is burned in sugar mills to produce sugarcane bagasse ash (SCBA), which is a silica-rich agricultural by-product [6]. The pozzolanic properties of SCBA contribute to the strength and durability of building materials. The viability of using sugarcane bagasse ash and cupola slag as the main raw materials for brick manufacture is investigated in this study. After being sieved to the appropriate particle size, the raw materials were combined in different amounts with 10% Ordinary Portland Cement (OPC) as a binding agent, and then they were molded into bricks [7–8]. The density, compressive strength, and water absorption of the bricks were evaluated and compared with the results of conventional burnt clay bricks.

The best performance among the tested compositions was exhibited by the M1 mix, which contains 55% cupola slag, 35% sugarcane bagasse ash, and 10% cement, with a density of 1529.77 kg/m^3, a water absorption rate of 7.0%, and a compressive strength of 3.32 N/mm^2. The results indicate the possibility of utilizing agricultural and industrial waste resources for the production of building products with high performance, affordability, and sustainability [9–10]. Cupola slag and sugarcane bagasse ash bricks meet key mechanical and physical requirements while resolving environmental issues by conserving natural resources and minimizing waste in landfills [11]. This study supports international initiatives to encourage sustainable building methods and the shift to a circular economy by providing an environmentally favorable substitute for conventional clay bricks [12]. As seen in Figures 1(a) and 1(b) [13], the slag was sieved using a 1.18 mm IS sieve to guarantee uniform particle size prior to being used in brick manufacture.

Fig. 1. (a) Cupola Slag before sieving (b) Cupola Slag after sieving.

As this material possessed the excellent compressive strength and was workable besides compatibility with all the other raw material constituents, the binder was thus the OPC Grade 53. So to keep constant each influence of concentrations of CS and SBA on its properties, all mixes contained constant cement content as 10%. The first preparation procedure for the brick specimen was to estimate how much raw material would be required based on the measurements of the brick mold, (190 × 90 × 90 mm) and the respective densities of the materials. To achieve uniform distribution, the basic ingredients were well mixed dry [14]. The mixture was hand-mixed to a uniform consistency and water then added gradually. After compacting mixture into molds, a piece of hardwood measuring 140 × 60 × 10 mm was used to make an indentation or frog in the bricks. In Figure 3, molded bricks are shown. The bricks were left to dry in the sun in a rain-protected shed after molding for seven days to ensure proper setting and curing.

Fig 2. Sugarcane bagasse ash dumped at Sugar factory.

II. MATERIAL AND METHOD

A. Raw Materials

- Cupola Slag (CS): Obtained from Neco Heavy Engineering & Casting Ltd., Nagpur, Maharashtra. This by-product, traditionally used for landfill purposes, was sieved to a uniform particle size (<1.18 mm).
- Sugarcane Bagasse Ash (SBA): Collected from Manas Agro Industries & Infrastructure Ltd., Bhandara, Maharashtra. SBA, rich in silica, was sieved and dried before use.
- Cement: Ordinary Portland Cement (OPC), Grade 53, was used as a binding agent in a fixed proportion of 10%.

Preparation of Brick Specimens

Brick specimens were prepared by mixing CS, SBA, and OPC in three different proportions:

- M1: 55% CS, 35% SBA, 10% OPC
- M2: 60% CS, 30% SBA, 10% OPC
- M3: 65% CS, 25% SBA, 10% OPC

The raw materials were dry-mixed to ensure uniform distribution. Water was gradually added, and the mixture was compacted into brick molds of size 190 × 90 × 90 mm. The molded bricks were dried under sunlight for seven days and then tested.

B. Test Methodology

Chemical contents of raw materials were analyzed out through X-ray fluorescence (XRF). An XRF spectrometer was used for elemental composition determination of cupola slag at VNIT, Nagpur. The specific gravity of the raw material was determined based on IS 2386 (Part III):1963. The particle size distribution of the cupola was studied as well. Block densities are based on IS 2185 (Part 1): 2005. IS 3495 (Part 1): 1992 was adopted to test the compressive strength of the cupola slag and sugarcane bagasse ash brick specimens. All the produced bricks were loaded under constant compression at a rate of 4 N/mm2 per minute till failure. Water absorption for bricks was determined by the weight of bricks soaked in water for 6 days and 24 hours sun dried brick specimens. A total of 18 brick specimens were made of different concentrations.

Mechanical Test

Compressive Strength: The compressive strength is determined in accordance with IS:3495. It measures the resistance of any material to crushing when a compressive load is gradually applied, as in the case of stone, brick, or concrete. The test is vital for establishing durability and structural performance in building materials. This test imposes a compressive force on a sample—be it cube, cylinder, or prism—until it fractures under the compressive strength of a testing machine. The compressive strength is the ratio of the maximum applied load during this test to the cross-sectional area of the specimen, which has been very well recorded. This, therefore, is important in ensuring that the material will be strong enough to give the required strength needed for building applications.

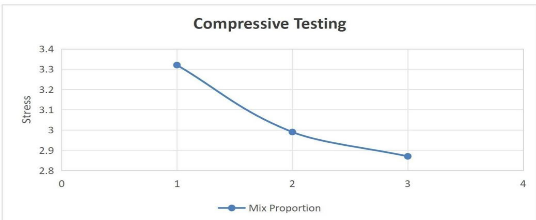

Figure 3

Absorption of Water: This test is carried out by immersing bricks in water for 24 hours, according to the IS:1077 standards

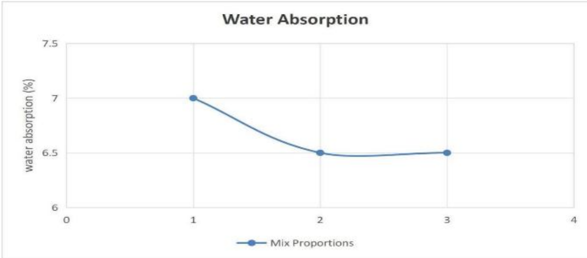

Figure 4

Density: The test is based on the standards of IS:2185. It measures the mass per unit volume of a material. This test would provide very vital information on the compactness and structural strength of the material; hence, density is one of the most important parameters in establishing the physical properties of aggregates, soils, or concrete.

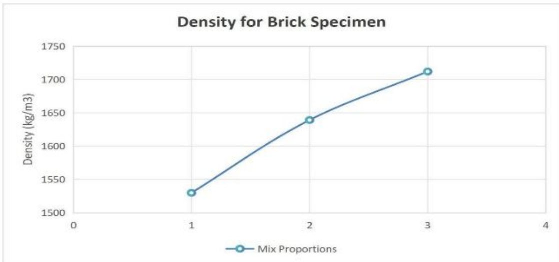

Figure 5

Chemical Test

XRF Analysis Test: Sugarcane Bagasse Ash (SCBA) and Cupola Slag (CS) can be analyzed by using X-Ray Fluorescence (XRF) to show their chemical composition and to prove their potential for industrial applications. CS has a little higher content of CuO, 0.07%, compared to SCBA with 0.014%. SCBA and CS have V_2O_5 values of 0.009% and 0.015%, respectively. Cupola Slag contains high silica with the composition 36.86% in CS and 35.103% in SCBA. In addition, there is considerable composition of CaO, 27.21% in CS and 3.859% in SCBA, and FeO_3 with 21.79% in CS and 3.287% in SCBA. Other oxides like AlO_3, KO_3, and MgO are also present in variable proportions to further increase the structural and chemical flexibility of the materials. Trace elements are PbO, TiO_2, and ZnO. Variation in processing and sampling of material reflects these variances. Results generally are supportive of the viability of both SCBA and Cupola slag as alternative construction materials to substitute conventional options, also as environmentally friendly alternatives for myriad applications.

XRD Analysis Test This is a non-destructive examination technique that will test phases and crystalline structure of materials. Information can be extracted by generating the diffraction pattern arising in crystal lattice upon exposing it to surface using an X-ray related to the structural feature of its purity. This technique is very useful in the identification of unknown materials and investigation of structural changes caused by processing or environmental influences. In this work, crystalline phases existing in Cupola Slag and SCBA were analyzed with the help of XRD, which established their suitability for building application. The results underline the importance of phase identification for the quality and performance of the material.

SEM Analysis Test: Surface appearance and microstructure of Cupola Slag and SCBA were tested by using Scanning Electron Microscopy (SEM). The present investigation showed that the two materials exhibit a porous texture and particles of irregular shape, which enhance binding when used in cement-based mortar. Furthermore, SEM images show microcracks and pore distribution that could be a critical factor affecting the mechanical performance of bricks. This study offers comprehensive knowledge of the materials through the incorporation of SEM and XRF. The SEM gives a visual insight into the microstructural features, which is helpful in predicting material performance in the manufacture of bricks, while XRF confirms the chemical appropriateness.

Thermogravimetric Analysis Test (TGA): TGA was conducted to determine the thermal stability of the materials of bricks and their decomposition patterns. The study of the research showed a number of steps of weight loss. The first weight loss, at lower temperatures, is attributed to the evaporation of moisture and the removal of loosely bonded water. Significant weight loss has been observed because of the decomposition of carbonates and calcium hydroxide at high temperatures to form cementitious compounds. The residual mass, at the end of the analysis, indicates stability of silica and metallic oxides that are responsible for maintaining the structural integrity of bricks at high temperatures. These results have pointed out the thermal resistance of the Cupola Slag and SCBA bricks, hence suitable for applications in building environments where better thermal performance is required.

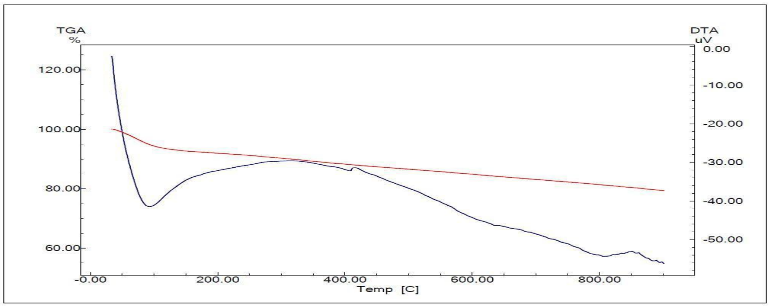

Figure 6 Results of Thermogravimetric Analysis Test

III. Results and Discussion

A. Properties of Raw Materials

Specific Gravity: The specific gravities of Cupola Slag (CS) and Sugarcane Bagasse Ash (SBA) are 3.30 and 1.90, respectively, showing the differences in their densities and material compositions.
Chemial Composition: Cupola Slag contained 36.86% silica and 7.5% alumina. The silica content in itself made the slag pozzolanic and accordingly, it could be a potential material for construction purposes. Sugarcane bagasse ash with more silica content 75.1% also had the tendency to act as an applicable additive to building materials to increase their strength and service life.

Table I - Chemical Composition

Sample Id	Formulas	CS	SCBA
SCBA	CuO	0.07	4.600
	V2O5	0.015	7.5
AND	SrO	0.005	1.22
CUPOLA SLAG	NiO	0.009	0.11
	PbO	0.001	0.23
	SiO2	36.86	-
	CaO	27.21	0.97
	Fe2O3	21.79	1.151
	K2O	4.600	3.818
	Al2O3	7.5	1.635
	MgO	1.22	1.598
	SO3	0.11	0.781
	P2O5	0.23	0.642
	TiO2	0.97	0.205
	MnO	1.151	0.132
	ZnO	0.01	0.017
	Cr2O3	0.104	0.015
	K2O	4.600	3.818
	Al2O3	7.5	1.635
	MgO	1.22	1.598
	SO3	0.11	0.781
	P2O5	0.23	0.642

Mechanical Properties of Bricks

Mix Design	Compressive Strength (N/mm^2)	Water Absorption (%)	Density (kg/m^3)
M1	3.32	7.0	1529.77
M2	2.99	6.5	1639.04
M3	2.87	6.5	1711.89

Compressive Strength: The M1 mix outperformed conventional burnt clay bricks ($3.5N/mm^2$), achieving 3.32 N/mm^2.
Water Absorption: M1 mix recorded the lowest water absorption (9.5%), meeting structural requirements. Density: M1 mix exhibited a density of 1608.18 kg/m^3, making it lightweight yet durable.

IV. CONCLUSION

The results show that SBA and cupola slag, as sustainable raw materials for brick making, are possible. Brick making can therefore be conducted by mixing industrial by-products of these industrial processes with a predetermined quantity of cement, and favorable mechanical and physical properties could be obtained experimentally.
M1 mix, containing 55% cupola slag, 35% sugarcane bagasse ash, and 10% cement, proved to be more excellent as compared to the other examined mix proportions. Its compressive strength was 3.2 N/mm^2, much closer to the value of traditionally burnt clay bricks having a 3.5 N/mm^2 strength. The M1 mix had a density of 1529.77 kg/m^3 and reduced water absorption rate of 3.32%, which are both good properties for durable building materials.
Using sugarcane bagasse ash and cupola slag in brickmaking is in order with the ambitions of smart cities and sustainable urban developments.
These bricks are suitable for the infrastructural needs of modern metropolitan cities since they provide a cheaper and sustainable alternative to traditional materials. This approach supports resource efficiency and waste management, two key aspects of smart city initiatives, while tackling two major environmental issues: reusing industrial and agricultural waste.
Advanced materials with such characteristics will also form part of developing strong urban infrastructure and energy-efficient structures that need to be put in place as the population in the city grows rapidly. It not only reduces environmental pollution but also nurtures the principles of a circular economy to ensure a pathway toward sustainable development and improvement in life quality within cities.

ACKNOWLEDGMENTS

Thank you to the Department of Civil Engineering, YCCE, for laboratory support.

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