Fusion Journal of Engineering and Sciences

Article

Use of Waste Marble Powder and Sugarcane Bagasse Ash in the Production of Bricks

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Abstract

Due to their structural stability, thermal drawback and their beauty, clay bricks have remained among the most used construction commodities. However, the old methods of producing bricks rely very much on natural clay which produces severe ecological degradation and drainage of fertile soils. As a solution to these problems, this paper dis- discusses the idea of using waste marble powder (WMP) and sugarcane bagasse ash (SBA) as partial substitutes of clay as a raw material in bricks making. Compressive strength, water absorption, efflorescence, soundness, and hardness were tested with the mixed proportions made in twenty-five mix combinations with the WMP/SBA contents of 0 to 40 per cent and the specimens were tested in line with the ASTM standards. The experimental results revealed that compressive strength gradually decreased with an increase in the content of waste particularly at higher content of SBA, nevertheless, water absorption and efflorescence did not surpass the tolerable limits of mixes with the maximum replacement of 30 percent combined. Besides this threshold, the performance reduced drastically with mixes of 20% SBA and 10% WMP experiencing the highest reduced strengthening. It is interesting to note that the source of WMP in Warsak Road, Peshawar, is local, and this fact also shows that the sustainable production of bricks can be producible in the region. This evidence suggests that even the combination of WMP and SBA by 30 percent can be combined without worsening the structural and durability requirements, which is a positive direction to the conservation of resources, using waste, and building in an ecologically friendly fashion.

Keywords: waste marble powder; sugarcane bagasse ash; sustainable construction; brick performance; resource conservation.

1. Introduction

In the case of urban growth and de-development of the economy, construction industry plays a significant role [1]. This is particularly the case in the emergent economies, in which rural to urban migration has been extremely high and thus necessitates massive infrastructural and housing demands [2]. A continuous shortage of affordable housing is one of the direct effects of such an increase. This has been increased by the rising costs of conventional construction materials which are comprised of steel construction materials, bricks, and cement [3]. Construction materials could take up to 60 percent of the remaining construction price, and this puts a lot of financial burden on the developers and final consumers [4]. In a bid to deal with the growing supply and demand, researchers, civil engineers, environmentalists, and policymakers are increasingly discovering other construction materials, which are less costly, energy saving and environmentally friendly.

The building material of bricks has a long history of building as it is extraordinarily strong, durable and is available in enormous quantities [5]. They can be easily transported, stored, and can be installed without the highly specialized labor required more often, due to them being modular. The conventional bricks are primarily composed of clay that have been moistened with water, moulded, fired in elevated temperatures, and made them hard and sturdy. Because of the above-mentioned, bricks have very vast use in load bearing walls, pavements, and structural elements. In Pakistan, like in most other developing countries, the brick masonry practice remains the mainstay of the construction business due to the easy availability of clay, cheapness in production and by virtue of the concomitant thermal insulating qualities. However, despite their widespread use, the traditional approaches to the manufacturing of bricks have created an enormous issue regarding the deterioration of the environment and long-term sustainability [6].

One of the most significant environmental problems with the production of bricks is the extraction of fertile topsoil that promotes the degradation of ecological conditions [7]. The uncontrolled surface run-off has a negative effect on agricultural productivity; a high soil erosion rate is realized [8]. In addition, firing bricks is a very energy consuming process that causes toxic pollution of the environment, including the following: carbon dioxide (CO_2), carbon monoxide (CCO) particles matter, and black carbon. It varies with the kind of kiln, averaging 70 to 282g of CO_2 to make a kilogram of brick and up to 5.78g of CO [9,10]. In addition to this, the energy consumed per kilogram of the brick varies between 0.54 and 3.14 MJ [11].

These effects are especially worrying considering that China, India, Pakistan, Bangladesh, and Vietnam produce more than 260 billion bricks in a year, which represents more than 75 percent of the world manufacturing of bricks [12]. As a result, the environmental footprint of the manufacturing industry of bricks are major threat to the eco-systems and health of the people in the region and the world.

Concomitantly, the case with the management of industrial and agricultural waste in Pakistan is growing increasingly stressful. Of interest in this regard is waste marble powder (WMP) and sugarcane bagasse ash (SBA) which are by-products of the marble and sugar industry, respectively. The amounts of these materials are huge, and they are most of the time disposed without treatment, contaminating the land, air, and water re- sources [13]. It is estimated that the country contains more than 300 billion tons of marble and onyx, with the Pakistani organization, Pakistan Stone Development Company (PASDEC) estimating that an approximate of 1 million tons of it is mined every month, with 45-50 percent of this amount found in Khyber Pakhtunkhwa region alone [14]. In attending to the processing, polishing and cutting of marble, it is approximated that approximately 20-30 percent of the raw material goes to waste in terms of slurry or powder, of which approximately a good percentage of it is directed to an open space or a stream of water [15]. This waste is dried and after drying, it is in the form of dust particles that disperse into air and damages agricultural land around the vicinity thus lowering the productivity of the soil and polluting ground water [16, 17].

This unrestrained waste disposal is a grave danger during rain fall as marble slurry will be mixed with water and percolated into the groundwater table or water bodies tangents to the surface. This is quite dangerous to their health, like respiratory complications due to airborne particles and kidney stones due to consumption of contaminated ground water. Regions such as Buner, Swat, Peshawar, and Nowshera are impacted because of the concentration of marble processing plants [18, 19].

Sugarcane bagasse ash (SBA) on the other hand is another waste that is problematic and manufactured by sugar mills throughout the country. Pakistan is an agricultural country and is also one of the largest producers of sugarcane in the world and her country produces approximately 50 mil-lion tons annually [20]. Sugar is extracted after which bagasse is burned to fuel boilers, because of which the fine ash is disposed of in landfills or emitted into the atmosphere. In Pakistan, almost 0.25 million tons of SBA are produced every year, and SBA is the cause of air pollution and respiratory diseases, particularly in urban regions of sugar mills because of low density and fine particle size [18, 21].

It is an issue of double trouble of excess solid waste generation and the steadily growing damage to the environment, which requires innovative solutions capable of utilizing these solid wastes in constructive ways. The engineers and researches across the planet are working towards the use of these solid wastes as an alternative to construction materials, in the process, they will meet their double objectives of minimizing the damage to the environment and developing construction materials that are not only sustainable but cheaper [22, 23]. In this context, the concept of WMP and SBA introduction in the production of the bricks could be an exemplary solution. A replacement of some of the clay with these solid wastes not only helps in preserving the topsoil, but there will be an additional saving in terms of energy cost and greenhouse gases released during the firing process. It will provide an exemplary solution in disposing of industrial waste in an efficient manner, reducing the burden of landfills [24, 25].

Numerous studies conducted worldwide have demonstrated that bricks made using a mixture of some clay with WMP and SBA can possess mechanical properties, including com-pressive strength and water absorption, which are comparable to those of normal bricks. Under some conditions, these modified bricks prove even superior in retaining heat and are more durable than the ordinary bricks [25-27]. However, to ensure that such types of alternatives can be used, then in-depth research must be conducted to compare various properties, including compressive strength, soundness, water absorption, efflorescence, and hardness, in the location of the planned use.

In this study, I aim to fulfill this need by conducting exhaustive experimental research on the structural bricks constructed using various quantities of WMP and SBA as part of clay replacements. The study will develop a replicable solution to the building sector in Pakistan, in terms of developing the optimal mix that meets both structural and durability requirements. The materials used in creating the bricks will benefit the environment and provide a cheap means of creating affordable homes. This will contribute to the national goals of development and the world environmental requirements.

2. Methodology

The aim of this study is addressed in the methodology section where the procedures and strategies were explained to achieve the objectives of the study. This is a full account of the experiment design, sample preparation and testing methodologies that were implemented to determine the effect of waste marble powder (WMP) and sugarcane bagasse ash (SBA) on the production of bricks when they are used as a partial substitute of the clay. The study used an experimental design that was piloted in the laboratory where the different concentrations of WMP and SBA were used on samples of bricks to explore their transforming effects on important physical and mechanical properties.

ASTM standards were used during the inquiry to ensure that sample was prepared stringently, kiln burnt under control, and standard lab tests like compressive strength, water absorption, and efflorescence were taken.

The description of the stepwise process of the research was presented in Figure 1 and includes the following steps: the acquisition of materials, sample production, quality testing of samples, and the analysis of results.

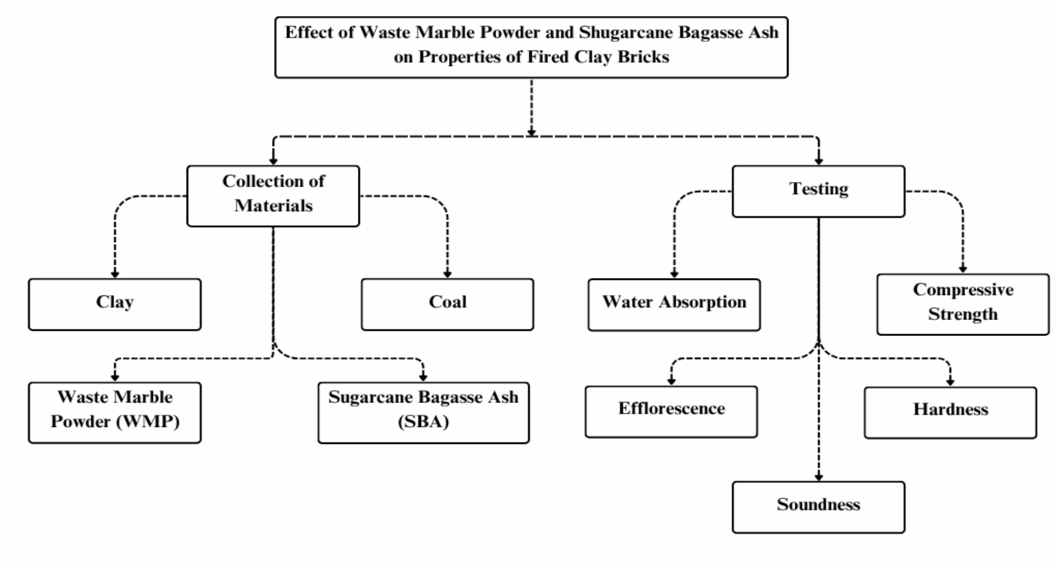

Figure 1: Methodology Flow Chart

2.1 Collection of Materials:

2.1.1 Waste Marble Powder (WMP):

Waste Marble Powder (WMP) is generated during the cutting, carvings, and polishing of marble stone. This waste material is mostly composed of fine fractions, which have a high proportion of calcium carbonate and are generated enormously. WMP is normally dumped at the landfills or open dumping grounds, posing significant concern to the environment, particularly soil and water pollution. However, due to the compositions, which have a high proportion of calcium oxide, silica, and other trace oxides, WMP has the potential to be qualified as a supplementary construction material. The use of WMP as a construction material would reduce the waste of the material, as it must use virgin materials, and would provide relief to the soil and water pollution caused due to the use of conventional methods of constructing buildings.

2.1.2 Sugarcane Bagasse Ash (SBA):

The residue of sugarcane stalks left in sugar mills after juice extraction is called bagasse; when it is burnt, it produces sugarcane bagasse ash (SBA). Tons of such bagasses are burnt every year, and their ash is thrown away randomly, either in the open fields or in coastal locations, leading to environmental degradation. Part of the base is also used as fuel in boiler mills in the sugar plants, which again results in additional SBA. Because it has a high silica content, reminded with other mineral oxides, SBA has enormous potential for use as a partial substitute for traditional construction materials. The use of industrial and agricultural waste in brick manufacturing is a good waste management initiative that has contributed to the diversion of the waste from dumping sites in addition to saving the natural resources and facilitating the use of environmentally friendly construction procedures.

2.1.3 Clay:

The natural clay used for brick production was sourced from nearby brick kilns located in Jalozai, Khyber Pakhtunkhwa. Prior to brick manufacturing, the clay underwent a standard preparation process, which included excavation, washing, air-drying, and tempering to achieve the desired workability and homogeneity.

2.1.4 Coal:

Locally sourced coal from the Darra and Hyderabad regions was employed as fuel in the brick kiln, facilitating a controlled burning environment at temperatures between 1000–1100°C.

2.2 Preparation of Brick Samples:

The samples made were 24 different brick compositions, which were made to examine the impact of partially replacing clay with waste marble powder (WMP) and sugarcane bagasse ash (SBA). Replacement levels were procedurally adjusted between 0-20 per cent of WMP and SBA whilst the overall clay content was kept at 100%. Five bricks were made within each composition, and this made 120 samples, which have provided statistical reliability on the results of the tests.

Table 1 sums up the proportions of mixes of the brick specimens in the form of waste marble powder (WMD) and sugarcane bagasse ash (SBA) as substitutes of natural clay in part. WMP and SBA replacement level on a case-by-case basis and as a group was ranged at 0-20 percent and total material content main-stayed at 100 percent. The control mix used conventional clay bricks to enable comparison of per-performance.

Table 1: Replacement of WMP and SBA by weight

Item	Replacement		
	WMP (%)	**SBA (%)**	**Clay (%)**
Conventional Bricks	0	0	100
M (5)B (0)	5	0	95
M (10)B ((0)	10	0	90
M (15)B ((0)	15	0	85
M (20)B (0)	20	0	80
M (0)B (5)	0	5	95
M (5)B(5)	5	5	90
M (10)B (5)	10	5	85
M (15)B ((5)	15	5	80
M (20)B (5)	20	5	75
M (0)B ((10)	0	10	90
M (5)B (10)	5	10	85
M (10)B ((10)	10	10	80
M (15)B (10)	15	10	75
M (20) B (10)	20	10	70
M (0)B (15)	0	15	85
M (5)B (15)	5	15	80
M (1) BB (15)	10	15	75
M (15)B (15)	15	15	70
M (20)B (15)	20	15	65
M (0)B (20)	0	20	80
M (5)B (20)	5	20	75
M (10)B (20)	10	20	70
M (15)B ((20)	15	20	65
M (20)B (20)	20	20	60

2.3 Manufacturing Process:

The brick preparation process involved four key processes that involved preparation of clay, molding, drying and kiln firing. At the clay preparation stage, the topsoil was initially stripped (un-soiling) that already contained contaminants and clean clay was excavated in the lower strata and piled in a depth of 600-1200 mm. This was the dug-up clay, and it was washed away with the assistance of the removal of stones and pebbles and organic materials and leaving it in atmospheric conditions over a couple of weeks, which could be done to make it more plastic. This was then fused and the broken clay was tempered by pouring a lot of water on it and stirring it deeply either by hand or with a pug mill, to keep a consistent plasticity. Molding It was in its turn done by the process of hand molding, the rectangular steel molds, selected in case of their cost-effectiveness and labor supply, each worker could produce about 1200 bricks per day. Bricks dried a day or so to remove wetness and once moulded, hence avoiding the cracking. Finally, the kiln was used to dry the bricks at 1000-1100degC with the use of coal that was produced locally. Each brick required around 24 hours to be fired in a continuous kiln and the whole kiln process was done in a span of 28 days after which its bricks were structurally sound to undergo further tests.

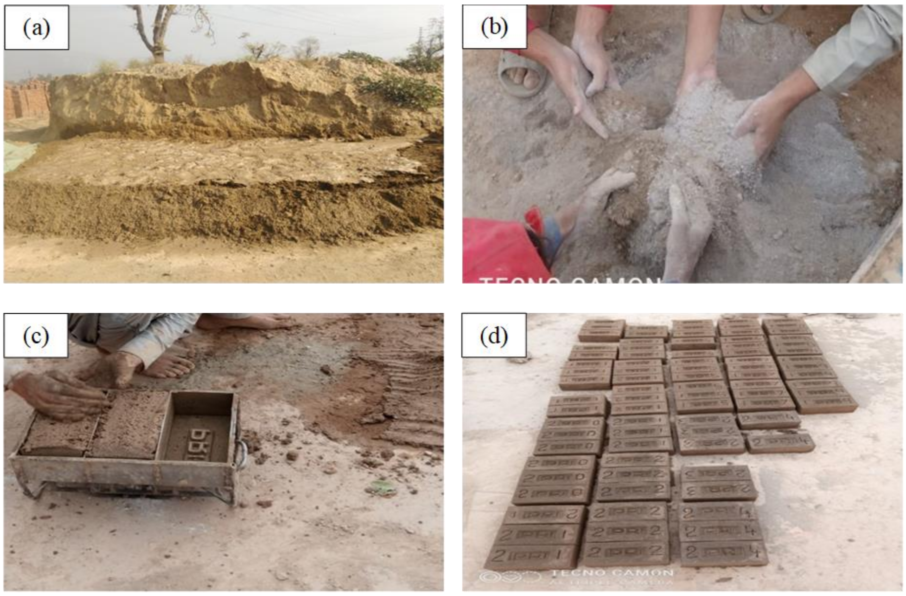

Figure 2: a) Prepared Clay, b) Mixing of materials, c) Molding of bricks, and d) Drying of bricks.

2.4 Testing of Brick Samples:

Following the manufacturing and kiln firing processes, laboratory tests were conducted to evaluate the properties of the bricks, including compressive strength, water absorption, efflorescence, soundness, and hardness. All tests were performed in compliance with ASTM C67-02c and ASTM C67-08 standards.

2.4.1 Compressive Strength Test:

Compressive strength of bricks determines how well the bricks are resistant to structurally carrying loads. The compressive test was conducted based on the ASTM C67 recommendations. The initial leveling of the brick specimens was followed by the accurate measurements of the specimen followed by immersion in the room temperature water during the period of 24 hours. The bricks were then dried after removal in water, and then the area was sur-surface dried, and any irregularities or frogs were filled to even the load distribution with 1:3 cement mortar. The bricks were then cut in half, and they were placed separately in a universal compression testing machine and incremental load was loaded on them until they failed. The compressive strength was determined in terms of the formula:

$$C = \frac{F}{A}$$

Where:

C = Compressive strength (MPa)

F = Maximum load at failure (N)

A = Cross-sectional area of the brick specimen (mm²)

Three samples per brick composition were tested, and average values were reported for analysis.

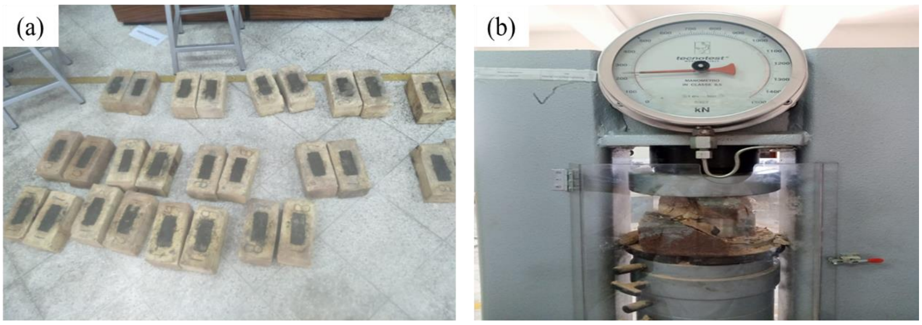

Figure 3: a) Frogs filled with mortar b) Compressive strength testing of brick sample using compressive testing machine.

2.4.2 Water Absorption Test:

The water absorption test determines a brick's resistance to moisture penetration, an indicator of durability and quality. Testing was conducted per ASTM C67-02c. Brick specimens were initially oven-dried at temperatures of 105–115°C until constant mass (M1) was achieved, then cooled to room temperature. Subsequently, bricks were immersed in water for 24 hours. After immersion, bricks were surface-dried and reweighed (M2). The water absorption value (%) was calculated using:

$$W = \frac{M_2 - M_1}{M_1} \times 100$$

Three specimens per composition were tested, and the arithmetic mean value was reported. Bricks were classified based on absorption rates, with maximum acceptable limits of 20%, 22%, and 25% for first-class, second-class, and third-class bricks, respectively.

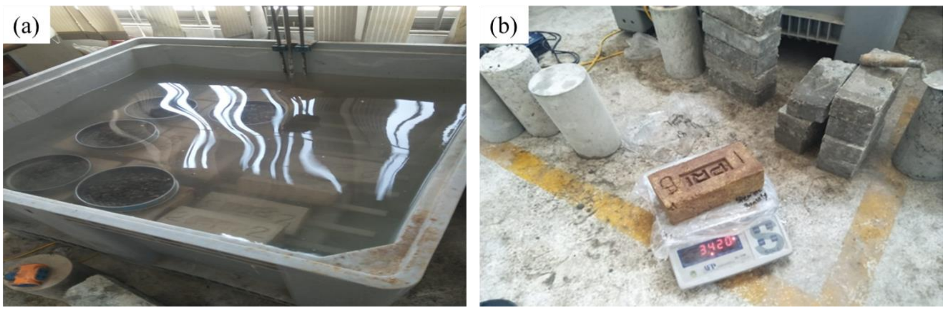

Figure 4: (a) Immersion of Brick Samples in Water for 24-Hour Curing (b) Measurement of Wet Weight of Brick Sample After Curing

2.4.3 Efflorescence Test:

Efflorescence refers to the crystalline salt deposits appearing on brick surfaces. This test was conducted as per ASTM C67-08 standards. Each brick specimen was immersed in clean water for 24 hours, removed, and then air-dried in a shaded environment. The bricks were visually inspected for the presence and extent of efflorescence deposits. The efflorescence was classified as:

- **Nil:** No salt deposits observed.
- **Moderate:** Salt deposits covering up to 50% of the brick's surface.
- **Heavy:** Extensive salt deposits covering more than 50% of the brick's surface.

Figure 5: Efflorescence test of bricks.

2.4.4 Soundness Test:

The soundness test, a qualitative assessment of brick integrity, involved striking two bricks together. Bricks producing a clear, metallic ringing sound were classified as sound and indicative of superior quality.

Figure 6: Soundness Test of Bricks

2.4.5 Hardness Test:

The hardness test assessed brick resistance to abrasion and general wear. The test involved scratching the brick surface using a fingernail. Bricks that resisted scratching with minimal or no visible impression were considered adequately hard and suitable for structural use.

3. Results

3.1 Compressive Strength:

The performance of the fired bricks in compressive strength in case of varying ratios of Waste Marble Powder (WMP) and Sugarcane Bagasse Ash (SBA) was assessed along the ASTM C67. The tabulated findings will be shown in Tables and Figures below. A clear declining trend in compressive strength was observed as the percentage of both waste materials, and this accounts for a direct correlation between an increment in the replacement level to a reduction in the load bearing capacity of the bricks.

The degree of compressive strength decreases when the content of the WMP was held constant, and the SBA altered was significant. As compressive strength was measured at 0% WMP, compressive strength was reduced by half between 0% SBA at 1614 psi and 20% SBA at 801 psi. The more there is WMP content, the more the adverse impact of the SBA. This is seen by the fact that strength 5 per cent WMP lowered to 540 psi (158 psi or 66 per cent), at 10, 15 and 20 Wmp, the strength dropped by 67.8, 71.6 and 77 per cent respectively as the SBA content rose to 20 per-cent. The specified tendency demonstrates the progressive effect of SBA and WMP on the improvement of the porosity of the matrix, the degradation of the bond between the particles, as well as the ultimate decline in compressive strength.

On the same note, compressive strength steadily declined as the SBA material was kept constant with WMP varied. In the case of bricks whose SBA was 0%, the strength dropped to 1614 psi (0% WMP) to 956 psi (20% WMP) which was 40.7%. But at 20 per cent SBA the same increase of WMP resulted in a more pronounced drop in strength, i.e., 801 psi down to only 219 psi, or the decrease of strength was about 72.7. This comparison indicated that the two additives had a negative impact on strength, but SBA was more dominant about structural degradation than WMP in equivalent level of substitution.

These results highlight the criticality of a proper balance between the amount of such waste materials to ensure the strength of the bricks within manageable structural limits. Though the use of WMP and SBA enhances the sustainability and using substances to valorize waste, overindulgence especially in combination causes higher porosity and lesser densification that eventually lowers the mechanical integrity of the bricks.

Table 2: Compressive strength of samples having constant WMP vs variable percentages of SBA.

	Sugarcane Bagasse Ash				
WMP %	0%	5%	10%	15%	20%
0%	1614	1554	1362	1189	801
5%	1588	1362	1092	869	540
10%	1377	1143	897	671	443
15%	1175	998	805	582	334
20%	956	892	749	460	219

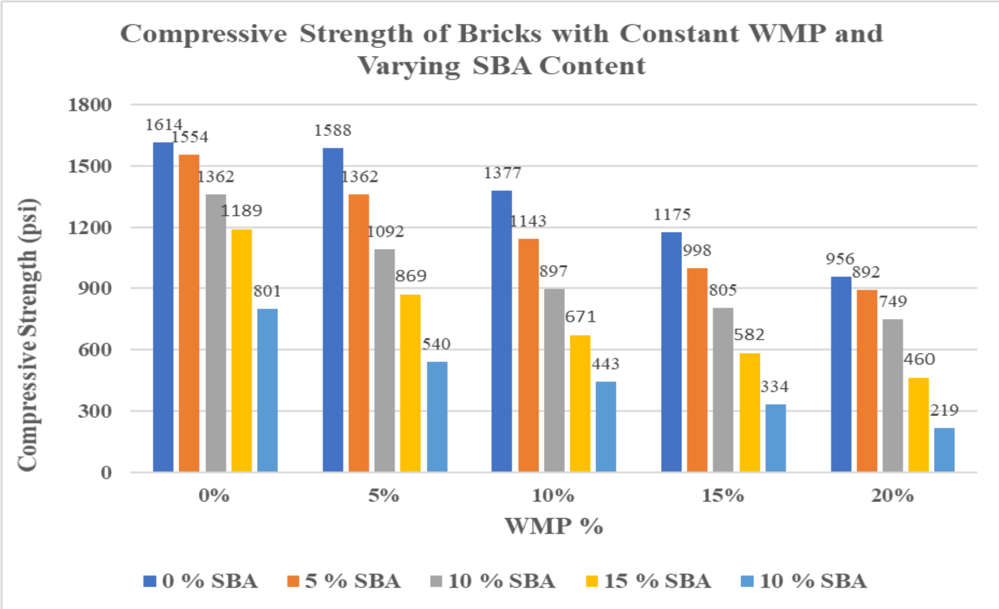

Figure 7: Column chart of compressive samples having constant WMP vs variable percentages of SBA.

Table 3: Compressive strength of samples having constant SBA vs variable percentages of WMP.

SBA (%)	Waste Marble Powder				
	0%	5%	10%	15%	20%
0%	1614	1588	1377	1175	956
5%	1554	1362	1143	998	892
10%	1362	1092	897	805	749
15%	1189	869	671	582	440
20%	801	540	443	334	219

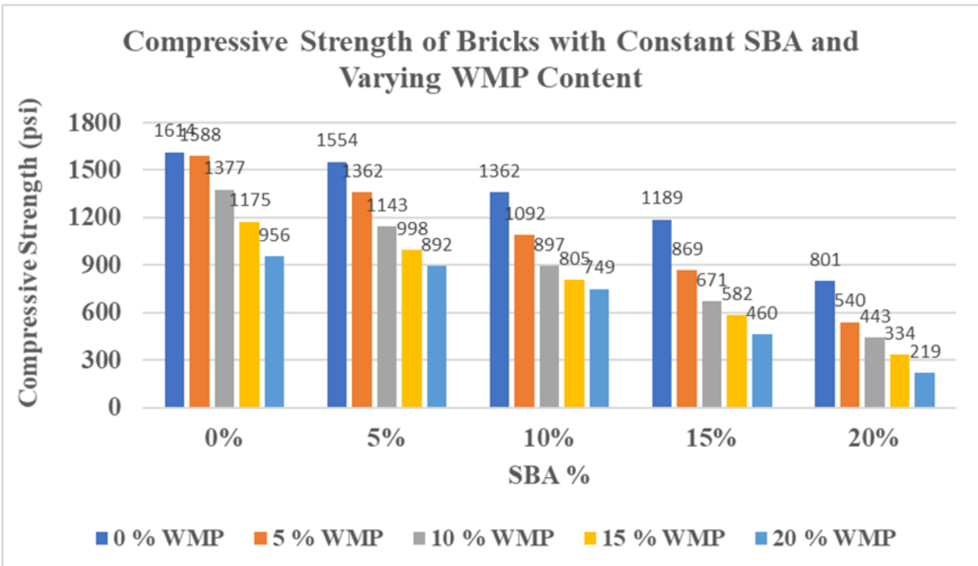

Figure 8: Column chart of compressive strength of samples having constant SBA vs variable percentages of WMP.

3.2 Water Absorption:

On the premises of ASTM C67, absorption characteristics of fired brick samples with different concentration of Waste Marble Powder (WMP) and Sugarcane Bagasse Ash (SBA) were investigated. As it would be observed in Table 4 and Table 5 and in Figure 9 and Figure 10, the trend is obvious and consistent, the larger the percentage of either WMP or SBA in the clay matrix, the larger the values of water absorption will be. Note this, with the constant WMP content, the SBA content was varied to high (0 20 percent) respectively, a greater increase in the water absorption was noted. In illustration, the absorption of water at 0% WMP increased between 12.9 to 17.31% with the content of SBA being varied in the range. Similarly, at 15 percent increase of water absorption at an increase was detected; between 14.54 percent absorption of water at 0 percent SBA as against 27.98 percent at 20 percent SBA. Such tendency means the porousness and less compactness of the more highly SBA-incorporated mixture. Being a light weight and quite porous pozzolanic material, SBA aids in the formation of more spaces within the brick matrix particularly at high re-placement ratios thereby facilitating easy penetration of moisture.

Conversely, the opposite reported trend occurred in the instance whereby the SBA content was kept constant and WMP content was increased. Indicatively, a rise of 20.4 percent rise in the absorption of water at 10 percent SBA was witnessed between 15.7 percent at 0 percent WMP and 20.4 percent at 20 percent WMP. This trend is explained by the attributive character of WMP not being cementitious, i.e., it can lead to the filling of the particles in the brick structure under excessive exploitation. Although the marble powder has a low pozzolanic activity, its fine texture can create interstitial pore sides and weak bonding between the clay particles that result in a more open microstructure that is susceptible to the absorption of capillary water. The maximum percentage of water absorption was recorded as 32.14 percent at 20 percent of level of WMP and 20 percent of level of SBA substitution- the maximum level of substitution. The matrix at this position was thinner and more porous. This revealed that the two waste additives mixed to decrease the density of the mixture.

It was found that bricks with low to moderate ratios (waste marble powder, WMP and the sugarcane bagasse ash, SBA) have water absorption values within acceptable ranges. Nonetheless, an increment in levels of replacement led to a high decrease in protection from moisture, which denotes a greater absorption of water. These results indicate the relevance of determining the best replacement ratios not only based on mechanical strength but also in terms of the performance criterion in terms of durability, especially the behavior of water absorption. In utilizing materials in wet or rainy climates, the overall behavior of the association between the material composition, porosity, and moisture transport is to be comprehended to promote long-term serviceability.

Table 4: Water absorption value (%) of samples having constant WMP vs variable percentages of SBA.

	Sugarcane Bagasse Ash				
WMP (%)	0%	5%	10%	15%	20%
0%	12.9	12.53	15.7	15.7	17.31
5%	13.1	13.67	17.1	18	20.2
10%	13.75	14.7	17.8	19.8	23.19
15%	14.54	15.96	19.4	22.4	27.98
20%	16.11	17.11	20.5	25.8	32.14

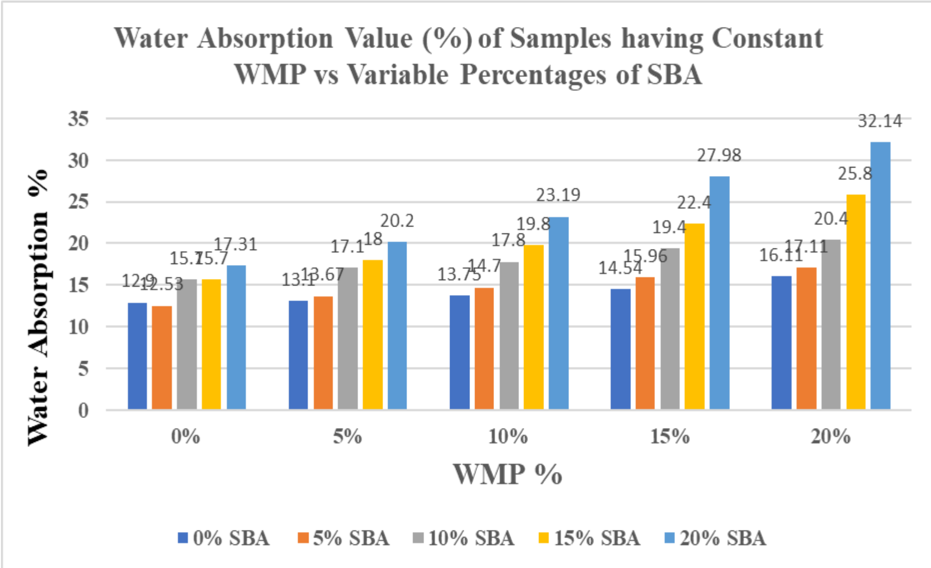

Figure 9: Column chart of Water absorption value (%) of samples having constant WMP vs variable percentages of SBA.

Table 5: Water absorption value (%) of samples having constant SBA vs variable percentages of WMP.

SBA (%)	Waste Marble Powder				
	0%	5%	10%	15%	20%
0%	12.73	13.1	13.75	14.54	16.11
5%	12.53	13.67	14.7	15.96	17.11
10%	15.7	17.1	17.8	19.4	20.4
15%	15.7	18	19.8	24.4	25.2
20%	17.31	20.2	23.19	27.98	32.14

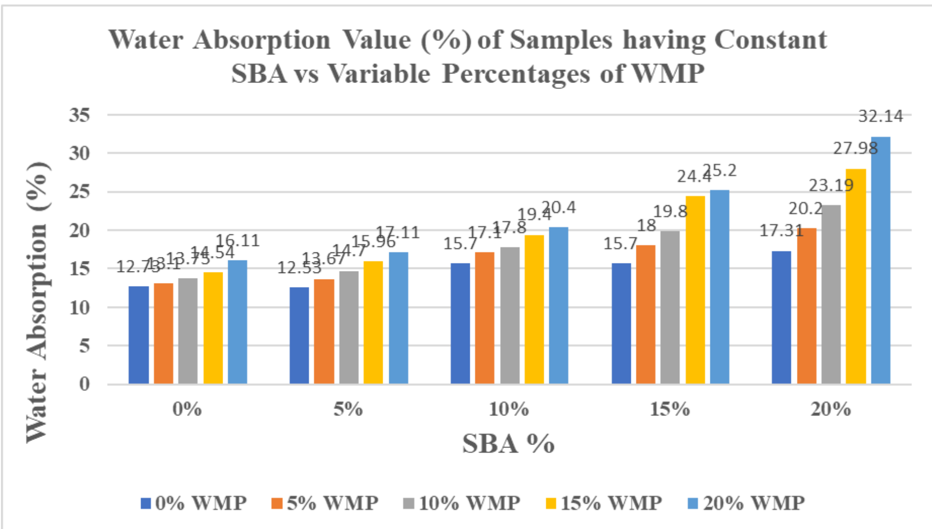

Figure 10: Water absorption value (%) of samples having constant SBA vs variable percentages of WMP.

3.3 Efflorescence Test:

The efflorescence behavior of the bricks was assessed following the ASTM procedure outlined. Results indicated that efflorescence was negligible at lower replacement levels of Waste Marble Powder (WMP) and Sugarcane Bagasse Ash (SBA). However, as the total amount of WMP and SBA rose beyond 30%, efflorescence became more noticeable. Samples of bricks that had been replaced less than 30% of the time had truly little salt deposits. This suggests they are resistant to efflorescence.

3.4 Hardness Test:

We used the ASTM approach, which is explained in the methodology section, to see how hard the bricks were. When pressed against anything hard, bricks with less than 30% combined SBA and WMP content did not show any obvious scratches on their surfaces. This showed that they had passed the test for hardness. Bricks containing more than 30% waste, on the other hand, revealed little scratches when scraped, which means they were less robust and resistant on the surface.

3.5 Soundness Test:

We hit two bricks together to test whether they were sound, which is what the ASTM says to do. Bricks, with up to 15% of SBA, A made a distinct ringing sound, which suggested they were robust and sturdy. But samples with more than 15% SBA made a dull sound, which might mean that the material is not as compacted or that there are tiny fractures within. Waste Marble Powder (WMP) did not seem to impact the soundness too much since the different WMP percentages did not have a substantial effect.

4. Discussion

This study and Munir et al. [25] are contrasted to demonstrate that the two experiments added waste marble powder (WMP) to clay bricks differently. Munir et al. studied the strength and durability of burnt clay bricks constructed using various proportions of recycled marble powder (RMP) of 5-25% and determined their durability. They found that incorporation of WMP increased the weight and reduced the tendency to shrink of the bricks, since it turned them more porous. However, once more the more WMP was incorporated the weaker the bricks became due to the breakdown in carbonate and the resulting gas that was formed during the burning process of the bricks which caused the bricks to become porous. As an example, using 25-percent WMP bricks was found to be 58 percent weaker when broken compared to bricks that had no WMP. Even today, bricks with as much as 10% WMP still complied with local requirements of the construction code on compressive strength.

In this study, however, the mixture of waste marble powder (WMP) and sugarcane bagasse ash (SBA was used. The compressive strength of the two types of trash also decreased as the amounts of these wastes increased. The result showed that the compressive strength significantly reduced when the total content of the SBA and WMP approached 30 percent. SBA affected strength as compared to WMP. This research is unlike the one conducted by Munir et al. since it focuses on the impact of the combination of two types of garbage on the efficiency of the machines. WMP was the primary focus of the research by Munir et al.

Munir et al. also perceived that the higher the WMP levels, the more porous it became, and this was to imply that it could hold higher water. It is what recent research revealed. In their study, Munir et al. reported a lower threshold (around 5% WMP) of appropriate water absorption levels (below 22%), when the weather conditions were moderate, whilst in this study the critical combined threshold (30% SBA and WMP) was observed beyond which water absorption grew above the suggested limits.

Table 6: Comparative Analysis of Brick Properties Between the Current Study and Munir et al.

Parameters	Munir et al. [25]	Current Study
Materials Used	WMP Only (0%–25%)	Combined WMP and SBA (0%–20% each; ≤40% total)
Compressive Strength		
Control Value	12 MPa (1740 psi)	1614 psi (11.1 MPa)
Optimal Mix	10 %WMP: ~10 MPa (1450 psi)	10% SBA + 5% WMP: 1143 psi (7.88 MPa)
Water Absorption		
Control Value	14.5%	12.73%
Optimal Mix	10% WMP: 17.6%	≤30% combined SBA & WMP: <20%
Efflorescence		
Low content (0-10%)	Negligible	Negligible (≤30% combined SBA & WMP)
Critical Threshold	≤10% WMP for optimal strength & absorption	≤30% combined SBA & WMP for optimal properties

Both studies also revealed that efflorescence was more deplorable when the waste material was more. Munir et al. clarified that this was since the calcium oxide (CaO) in the marble powder was excessive thus making the soluble salts fall out of the air. Equally, the present study determined small efflorescence among waste mixtures below 30%, and more visible effects were evident between high substitution levels. This highlights the importance of reducing the overall waste level to ensure efflorescence resistance and surface longevity.

Conversely, Kazmi et al. (2016) [28] examined bricks that were produced using SBA content in the form of 5%, 10 and 15 percent by weight of clay content. They also noted that there were reduced compressive strength with increased SBA inclusion. It exhibited moderate reduction (approximately 14% lower than control) in 5% SBA bricks and still retained compressive strength of approximately 7.18 MPa (1041 psi) which is within the range of acceptable compressive strength of structure bricks according to the requirement of Pakistani standards. Nevertheless, additional additions to SBA content (10% and 15) resulted in about half strength decrease relative to control bricks because of augmented porosity and decreased density. Likewise, the water uptake rose by a substantial percentage of 17 percent (control) to about 26 percent at 15 percent SBA, which is above ASTM guidelines of average weather type (>22 percent). Kazmi et al. also reported higher efflorescence resistance at all levels of SBA, which was explained by lower calcium oxide concentration.

The two studies found that the increment of the percentage of sugarcane bagasse ash (SBA) negatively affects the properties of the brick, especially the compressive strength and the water absorption. The present study revealed that compressive strength got reduced by about 50 percent on a 20 percent SBA replacement, and Kazmi et al. (2016) had found a reduction of compressive strength by about 50 percent at 10 to 15 percent SBA replacement. Likewise, the rise in water absorption was high when SBA content was high in both studies reaching 17.31% at 20% SBA in the present study and approximately 26% at 15% SBA in Kazmi et al. (2016). These two studies have emphasized the importance of limiting the content of the SBA (preferably less than 10% to have optimal performance of bricks and structural integrity).

Table 7: Comparative Analysis of Brick Properties Between the Current Study and Kazmi et al. (2016)

Property	Current Study	Kazmi et al. (2016)
Materials used	SBA & WMP	SBA & RHA
Compressive Strength	Reduced by ~50% to 20% SBA	Reduced by ~14% (5% SBA), ~50% (10%-15% SBA)
Water Absorption	Increased from 12.9% to 17.31% (0–20% SBA)	Increased from 17% to ~26% (0–15% SBA)
Optimal SBA Content	≤ 10% recommended	≤ 5% recommended
Efflorescence	Increased significantly after combined SBA & WMP exceeded 30%	Reduced at all SBA content levels

5. CONCLUSION AND RECOMMENDATIONS

5.1 Conclusion:

This study investigated the performance of fired clay bricks partially substituted with waste marble powder (WMP) and sugarcane bagasse ash (SBA). Multiple mix groups were prepared with varying replacement percentages, and the resulting bricks were subjected to a series of physical and mechanical tests to assess their performance relative to conventional clay bricks. The key findings from these experimental evaluations are summarized as follows:

- The incorporation of WMP and SBA in brick production offers an environmentally sustainable solution by mitigating the negative impacts of industrial waste disposal. This process not only reduces the quantity of marble debris and bagasse ash that builds up, but it also keeps natural clay resources safe.
- You may utilize debris from manufacturing marble and processing sugarcane to build bricks. This is helpful for the circular economy since it supports the move from waste to useful things.
- The compressive strength usually went down as the quantities of WMP and SBA got up. SBA made the strength decrease worse than WMP did. Bricks that had up to 20% of each material on its own were still strong enough. But when the two materials were combined and made up more than 30% of the bricks, the compressive strength values went below the acceptable thresholds. Mix B20M10 was different from the others since it didn't perform well in terms of strength even though it had a 30% combined replacement.

- Water absorption values increased with the addition of WMP and SBA. For most mixes, absorption remained within acceptable limits when the total replacement level was ≤30%. However, the B20M10 mix again deviated from this trend, showing higher-than-expected water absorption, due to increased porosity or poor particle bonding.
- Hardness tests showed that bricks with a combined WMP and SBA content of ≤30% exhibited no visible surface impressions when scratched with a fingernail, indicating good surface hardness. Beyond this threshold, light impressions became visible, reflecting a decline in material compactness and strength.
- The bricks produced a clear metallic sound when struck together if SBA content was ≤15%. Above this level, particularly at 20% SBA, the sound became dull, signaling the development of internal microcracks or reduced structural cohesion. WMP had a negligible impact on soundness.

5.2 Recommendations

Each country stands to benefit from contributing to environmental protection and the sustainable utilization of natural resources. Based on the findings of this study, the following recommendations are proposed:

- The use of waste marble powder (WMP) and sugarcane bagasse ash (SBA) as partial replacements for clay should be encouraged in local brick manufacturing industries, where marble waste generation is significantly high. Utilizing these waste materials in brick production can help reduce the environmental burden associated with landfill disposal and river pollution.
- A combined replacement of up to 30% WMP and SBA is recommended for optimal performance, except for the B20M10 mix, which exhibited lower compressive strength and higher water absorption. Beyond the 30% combined threshold, compressive strength dropped below acceptable limits, and water absorption exceeded recommended values.
- Since SBA has a more pronounced negative impact on compressive strength compared to WMP, it is advisable to limit SBA content and compensate with a higher proportion of WMP—within the 30% combined replacement range—to achieve better mechanical performance in the final brick product.

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