Producing eco-friendly and durable clayey bricks by substituting clay by waste brick and ceramic powders

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Abstract. Present investigation focuses on the recycling of wastes from brick and ceramic factories as a fractional substitute for clay in the production of clay bricks. The heavy reliance on clay in brick manufacturing is leading to the depletion of fertile land, contributing to environmental and climate concerns. The substitution rates of 5, 10, 15% for brick and 4, 8, 12% for ceramic are explored. The brick samples were assessed based on their mechanical performance and durability characteristics. The comparison of control and modified bricks depicted that the modified bricks performed well in water absorption and sulphate resistance characteristics.

Keywords: Clayey bricks, brick powder, ceramic powder.

1 Introduction

Bricks are extensively used in the construction industry. According to an estimate, 27 million bricks are produced in Mirpur city of Azad Jammu & Kashmir [1]. This is adversely affecting the environment. There is a need to mitigate the environmental impact by exploring novel materials, which are eco-friendly and can replace clay. Several authors have explored different materials as a fractional substitute of clay in making brickmaking. Some important research is documented here.

Kazmi et al. incorporated ashes of sugarcane bagasse and rice husk as partial substitutes for clay in brickmaking [2,3]. Their investigation showed that the substitution reduced the mechanical strength; however, the replacement reduced the density and the efflorescence effects. The porous bricks offer more resistance against temperature effect. Riaz et al. recycled pulverized brick rubble as a fractional alternative for clay in manufacturing clayey bricks [4]. The study documented that 25% replacement marginally reduced the strength and enhanced the resistance against efflorescence and heat transfer. The substitution also reduced the density by enhancing the pore volume. Riaz et al. recycled trash finely ground ceramic as a fraction of clay [5]. Their study revealed that the alternate material improved the mechanical strength, density, and durability of the material. Munir et al. employed waste marble powder in place of clay in bricks [6]. The authors depicted that the replacement reduced the strength, and density and enhanced resistance to efflorescence and sulphate attack. Khitab et al. employed a mixture of ceramic powder and brick powder as a fractional alternate of clay in brickmaking [7]. The finding showed that a substitution of 9% (5% brick powder and 4% ceramic powder) enhanced the mechanical strength. The researchers have further reported that the substitution also enhanced the resistance against freeze and thaw, sulphate attack and efflorescence.

The present study is an extension of the prior studies performed in our lab. Previous investigations employed a blend of fine brick and ceramic waste powders as a partial alternative for clay in brickmaking. The study suggested that the combination reduced the strength of the bricks after 9% combined replacement. Another two past studies suggested that the fine brick powder reduced, while the course ceramic powder enhanced the mechanical strength [4,5]. Consequently, this study was designed to recycle a combination of finely ground brick and coarsely ground ceramic as a fractional substitute of clay in manufacturing climate-friendly building blocks. The substitution levels were decided as 9% (5% brick + 4% ceramic), 18% (10% brick + 8% ceramic), and 27% (15% brick + 12% ceramic). The brick samples were assessed through water absorption, flexural strength and sulphate resistance.

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2 Materials and methods

Fertile Clay (C), Waste Brick Powder (WBP), and Ceramic Powder (CP) were employed as the raw materials used for manufacture of bricks. The materials are shown in
Fig. 1.

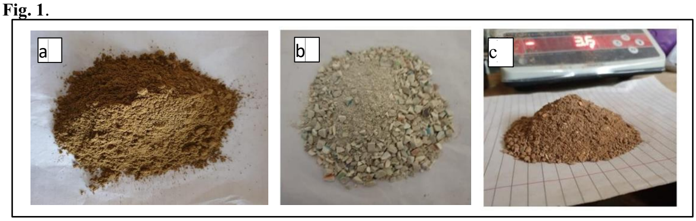

Fig. 1 Primary materials for making bricks (a) clay, (b) ceramic powder, (c) brick powder.

Table 1. Chemical composition of raw ingredients

Oxides	Clay (%)	WBP (%)	CP (%)
SiO_2	59.2	46.4	71.0
Al_2O_3	16.6	29.7	21.9
CaO	13.1	4.9	3.7
Fe_2O_3	6.9	7.8	1.2
ZrO_2	2.9	4.9	1.1
K_2O	0.9	3.9	0.4
CeO_2	0.1	5.2	0.3
MnO	0.04	0.05	0.11
CuO	0.02	0.01	0.02

The composition revealed that all the ingredients contained the same basic compounds as are required in clay suited for brick making. Nevertheless, the proportions are different. The XRD study is mentioned in Fig. 2. The analysis suggested that the clay mainly contained Alumina, lime, and Quartz; the WBP mainly consisted of Alumina, lime, Iron oxide and Quartz; and the CP was mainly comprised of Quartz. Thus, the XRF and XRD studies are closely inter-connected.

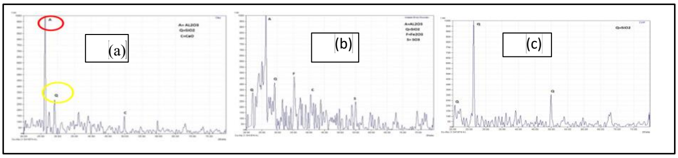

Fig. 2 X-ray diffraction images of (a) Clay, (b) WBP, and (c) CP

The material configuration of brick specimens is presented in **Table 2**. Forty brick specimens were made in each category. Also in each case, the same amount of water, i.e. 52 liters, was used.

Table 2: Composition of brick specimens

ID	Composition	Clay (kg)	WBP (Kg)	CP (Kg)
C0	Control	140	0	0
C4	4% CP & 5% WBP	127.4	7	5.6
C8	8% CP & 10% WBP	114.8	14	11.2
C12	12% CP & 15% WBP	102.2	21	16.81

The mixing and manufacturing of bricks is shown in Fig. 3. The bricks were manufactured in a local Bull's Trench Kiln [8].

Fig. 3 Manufacturing of clayey bricks

The specimens were tested for flexural strength, water absorption, and resistance to sulfate attack in compliance with ASTM standards. Flexural strength and water absorption were measured in accordance with ASTM C67 standards [9]. While, the sulphate resistance was assessed through ASTM C1012 method [10].

2.1 Flexural strength (Modulus of rupture)

The flexural strength was determined in accordance with ASTM C67-17. The parameter was determined by applying a four-point loading setup in the compressive strength machine. The load was transferred to the specimens through loading plates. The load rate was fixed as 8.4 KN/min. In the end, flexural strength or Modulus of Rupture (MoR) is calculated by equation (1):

$$\mathbf{MoR = \frac{3PL}{2wh^2}} \tag{1}$$

In this context, *MoR* represents the modulus of rupture evaluated in MPa, *P* is the load at which failure occurs (in Newtons), *L* denotes the length of the bricks (in millimeters), while *h* and *w* refer to the depth and width of the bricks, respectively, also measured in millimeters.

2.2 Water absorption

Water absorption capacity was measured using the ASTM C67-17 method. Specimens were first oven-dried, weighed, and subsequently dipped in water for 24 hours. Once the time had elapsed, the specimens were extracted, gently surface-dried, and subsequently weighed again. The rate of moisture absorption (S) was computed using the equation (2).

$$\mathbf{S = \frac{(W_s - W_d)}{W_d} . 100} \tag{2}$$

Here, W_s denotes the weight of the bricks when fully saturated, while W_d indicates their weight in a dry state.

2.3 Sulphate resistance

The chemical resistance of the bricks was assessed using the ASTM C1012 method. Bricks were dipped in 10 % solution of H_2SO_4 for one hour and a change in compressive strength and weight loss was observed.

3 RESULTS AND DISCUSSION

The results and their analysis are described in the coming paragraphs.

3.1 Flexural strength

Fig. 4 illustrates the relationship between flexural strength and waste content.

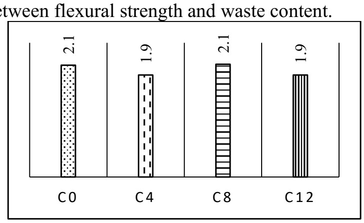

Fig. 4 Variation of flexural strength with waste content

It seems that there is almost no effect of waste content on the flexural strength. This characteristic is of significance if the bricks are meant for arches or curved surfaces. Flexural strength is a measure of inter-particle force of attraction. The results showed that the waste content does not affect the cohesion of the brick.

3.2 Water absorption

Water absorption of the brick specimens was determined following ASTM C 67-17. It was observed that water absorption decreased with higher waste content, suggesting improved compactness with the addition of waste materials. Specifically, the absorption rates of the bricks slightly decreased with increasing proportions of Waste Brick Powder (WBP) and Ceramic Powder (CP) compared to the control bricks.

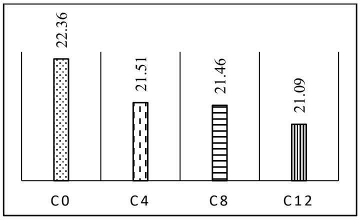

Figure-5: Variation of water absorption with waste

3.3 Sulphate resistance

The sulfate attack resistance of both control and modified brick specimens was assessed using the ASTM C1012 method, with results illustrated in Fig. 6. After one month of immersion in sulfate solution, the strength loss was recorded as follows: 1.55% for the control, 1.30% for 4% Ceramic Powder (CP) and 5% Waste Brick Powder (WBP), 1.02% for 8% CP and 10% WBP, and 0.72% for 12% CP and 15% WBP. These findings indicate that the sulfate resistance of the modified bricks improved with increasing waste content.

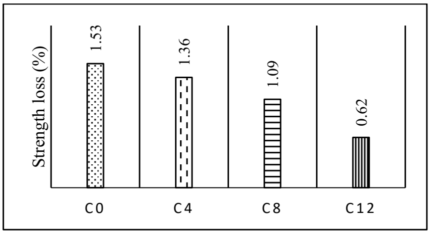

Fig. 6 Variation of sulphate resistance with waste

The sulphate resistance is dependent on the porosity of the material. High porosity leads to more damage as a result of a chemical attack [11]. Water absorption values in Figure 5 suggested that the waste content reduced the water absorption, which is a measure of the porosity of the material. Thus, the sulphate resistance and water absorption values are closely inter-linked.

4 Conclusions

1. The blend of brick and ceramic powders seemingly had no detrimental impact on the modulus of rupture of the bricks.
2. Integrating by-products resulted in lower water absorption rates for the bricks compared to the control specimens.
3. The inclusion of trash materials enhanced the bricks' resistance to sulfate attacks when compared to the control group.
4. The observed reductions in water absorption and improved sulfate resistance signify greater durability. Thus, the partial substitution of clay with a mixture of brick and ceramic powder has notably enhanced the overall durability of the bricks.

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