



Utilization of Marble Wastes in Clay Bricks: A Step towards Lightweight Energy Efficient Construction Materials

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Abstract

Marble dust is one of the hazardous byproducts of marble-processing factories and requires planned disposal. Its beneficial use as a construction material will add to the sustainability, and most importantly, might overcome the burden of marble waste disposal. However, the use of marble dust in concrete has a negative impact. Therefore, this research examines various properties related to the utilization of such material in ceramic clay, and therefore its effects on the use of clay bricks are investigated. The research activity covers the categorization of marble dust powder from three different sources: Ziarat in Mohmand Agency, Buner, and Mullagori (Pakistan). Its utilization in different proportions preparation of bricks is also addressed. Through the partial replacement of clay with marble dust from 0 to 30% by weight with amplification of 5%, seven mix designs are examined. The test result includes Bulk density, water absorption, porosity, thermal insulation, and strength. The partial replacement of clay with marble dust reduced its weight, strength and increased its porosity, water absorption, and thermal insulation. Furthermore, the utilization of marble powder in bricks minimizes soil erosion and reduces pollution to the environment.

Keywords: Marble Dust; Bricks; Compressive Strength; Thermal Conductivity; Porosity.

1. Introduction

Bricks are extensively used in the construction industry in Pakistan due to the local availability of clay, their aesthetic appearance, low cost, thermal insulation, and ease of transportation. Approximately 1391 billion bricks per year are utilized worldwide, and its demand is expanding [1]. Nevertheless, the clay deposits excessive use in brick production has depleted this natural material and is also the root cause of wastage of fertile land [2]. Nowadays, many developing countries face severe waste management issues caused by the increasing population, urban and industrial development [3]. Therefore, the reuse of waste in the construction industry has gained the attention of researchers.

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Utilizing various waste in infrastructure development has proven eco-friendly and economically viable [4, 5]. Many research studies have been performed on environmental preservation and sustainable development by efficiently utilizing various waste residues in bricks' production. These wastes include bottom ash, fly ash, blast furnace slag, saw-dust, furniture waste, crumb rubber, tea waste, rice husk ash, sugarcane bagasse ash, cotton waste, and limestone [6, 7].

Limestone (calcium carbonate) is the most imperative manufacturing material used for decorative purposes and is quarried worldwide, having various colors, thicknesses, and grain sizes. One of the naturally occurring kinds of limestone is marble, used in the stone industry. A large amount of micro-fine dust is produced in these industries during the cutting and polishing of marble stones. Approximately 20% of marble blocks are reduced to micro-fine powder, varying with the processing technology. In 2011 total world production of these dimension stones was higher than 68 metric tons [5]. After these stones were processed, it led to a yearly output of more than 30 Mm³ of marble dust resulting in landfill environmental problems [8]. There are numerous sites of marble in Pakistan. According to an estimate of the Pakistan Stone Development Company (PASDEC), more than 300 billion tons of marble are available. The country's whole monthly marble production is about one million tons, 50% of which comes from the mineral-rich province Baluchistan. About 0.45 to 0.52 million tons of marble are produced in Khyber Pakhtunkhwa [9]. To cut and polish, marble blocks are dispatched from quarries to processing units that make waste, such as dust and slurry. Generally, the marble waste is dumped in open spaces, which flows and falls to open drains, causing the blockage of drainage systems and polluting the drinking water reservoirs in Pakistan. The marble wastes carried away by rainwater and air to clean water reservoirs cause damage to human and aquatic life [10, 11].

Moreover, the open dumping of waste marble powder contaminates the surrounding environment, decreasing agricultural land productivity [12]. The volume of waste from marble processing increases day by day to congregate a growing population's demands. Most importantly, the environmental set of laws becomes more restrictive; thus, new options for utilizing these wastes need to be determined. Therefore, the civil engineering construction industry is thought to be one of the possible ways to use/recycle this waste [13]. Thus, researchers' admired trend has been to incorporate waste from marble industries in fired clay bricks. According to Sutcu et al. (2015), the increase in percentage addition of marble powder in clay bricks decreases the thermal conductivity to 0.401 W/mK from 1.014 [14, 15]. The optimum compressive strength was achieved at a replacement level of 5%, around 93.9% of the control specimen at the heating temperature of 105 °C. Munir et al. [16], the research highlighted that a replacement level of 15% showed satisfactory performance in improving compressive strength. Furthermore, the authors recorded a 16% reduction in the thermal conductivity of the fired brick.

The local municipal administration and the marble factory owners are in serious concern about controlling the hazards of marble waste. On the other hand, the solution to this waste's pollution problem, the construction industry today, is looking for locally available, cheaper, sustainable, and eco-friendly building materials. Marble waste as a construction material will solve the contamination problem and be a novelty in construction materials. In this research paper, an attempt has been made to evaluate different marble dust properties used in bricks. It is aimed that this research work will gain the trust of local administrations and will encourage the local builders to consider the marble waste as a construction material. Researchers have also tried to evaluate the properties of marble waste in different manners. However, an extensive research study is needed with a separate mechanical and physical property evaluation to develop a strong consensus. This research study will introduce a novel material to the construction industry, available abundantly in the world's queries and industrial zones [2].

2. Experimental Program

The marble waste material used in this research work is obtained from locally available quarries located in Khyber Pakhtunkhwa, Pakistan, namely Mohmand Agency (M.A.), Buner Region (B.R.), mix sample of Ziarat and Mullagori (Z-M). The general location of these marble waste materials in the Pakistan Map is shown in the Figure 1. The legends in Figure 1 show all places from where marble powder samples were collected for this study.

Clay sample is also taken from the kiln (located in Peshawar) in which these special bricks from marble dust were prepared. The odd size blocks of marble in quarries are disposed of in vacant spaces. Since there is no systematic way of disposal of this waste, vast amounts of wastes are generated. Also, the factories' waste is in the form of a slurry, which is a burden on the environment. The wastes from quarries and factories are shown in Figures 2 and 3. Thus there is always a need to utilize this waste on some excellent work properly.

For phase identification, chemical composition, and grain size distribution of each source of marble dust sample and clay, X-ray diffraction (XRD), X-ray fluorescence (XRF), and fineness tests were carried out in laboratories.

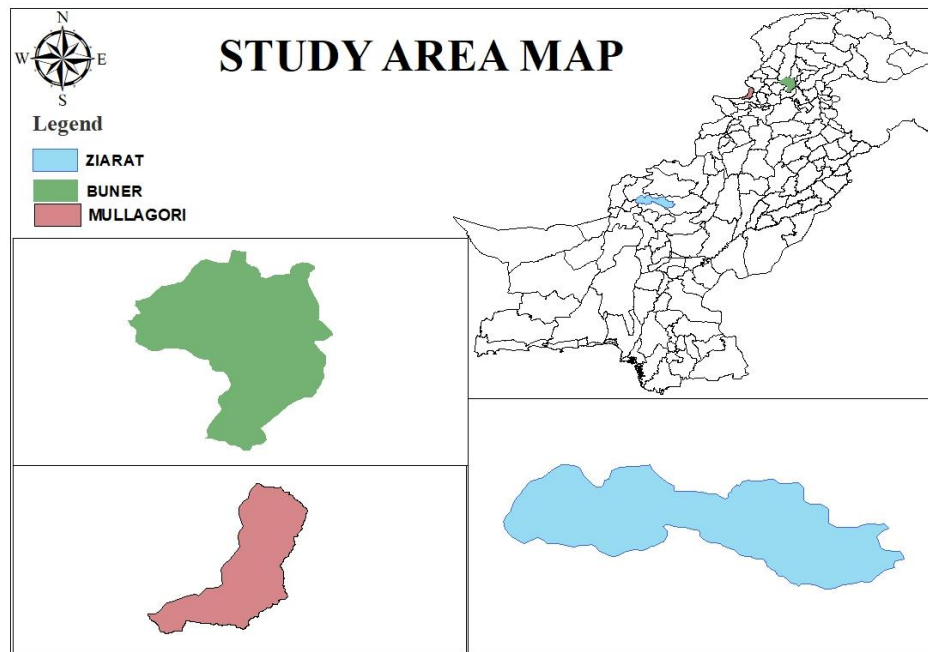


Figure 1. Locations of Marble Powder Samples

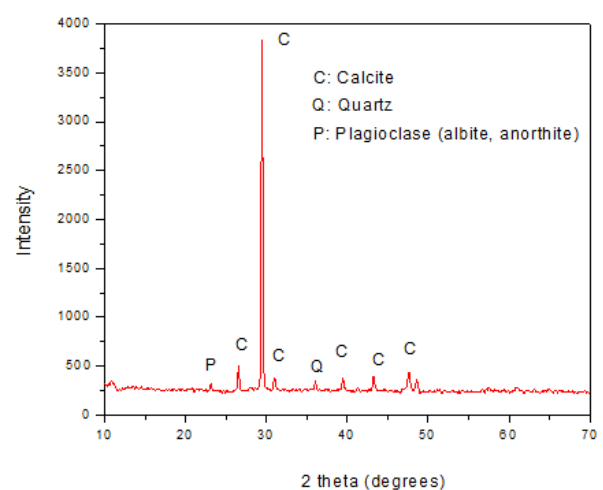
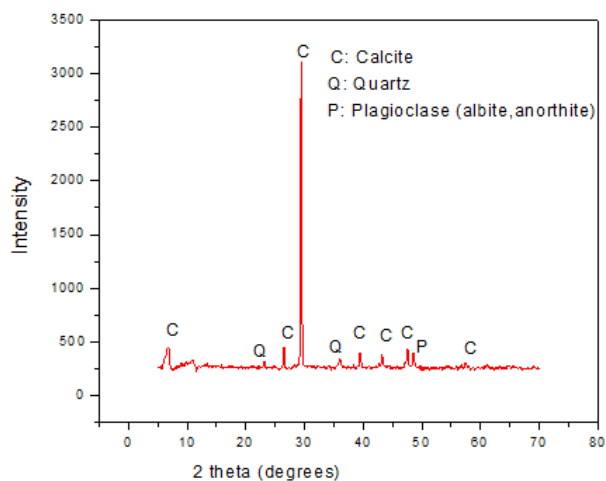


Figure 2. Waste in a quarry, Mohmand Agency, Pakistan



Figure 3. Waste (Slurry) in a factory, Pakistan

The X-ray diffraction tests were carried out in Geoscience advance research laboratories, Islamabad, Pakistan. According to the XRD analysis shown in Figure 4, the main phases in the marble dust are calcite (CaCO_3), quartz (SiO_2), and minor phases of plagioclases (albite, anorthite). The clay includes mainly quartz, illite/muscovite, clinocllore, and a small number of calcite phases.



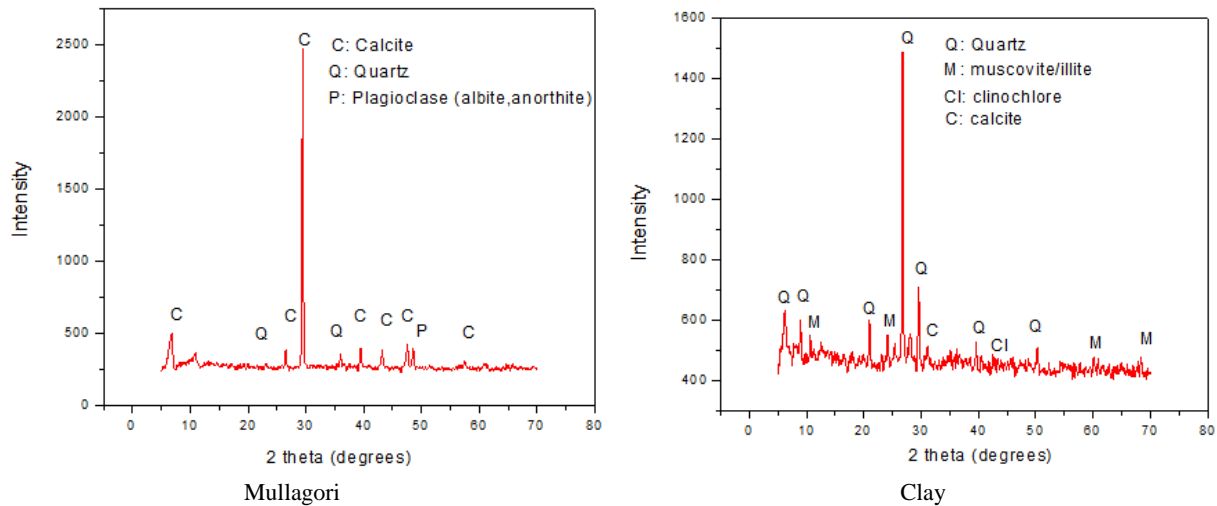


Figure 4. X-ray Diffraction patterns of clay and marble dust samples

The X-ray fluorescence [17] tests were carried out in Geoscience-Advance-Research-Laboratories, Islamabad. The X-ray fluorescence analysis was carried out on Axios Advanced WD-XRF for all the significant elements using a glass bead. For every three samples of marble powder, CaO content is greater than 49%. MgO content is less than 2.6%, indicating that all three samples are of calcite-type marble. The soil used to prepare bricks has SiO₂ and Al₂O₃ content greater than 49% and 15%, respectively, indicating that the soil can be used to make fired ceramic material. The sintering components (MgO, Na₂O, and K₂O) are less in percentages, creating difficulty in the configuration of liquid phases at high firing temperatures. The overall results are given in Table 1.

Table 1. Chemical composition of clay and marble dust samples (XRF analysis)

Major Elements (wt. %)	Marble Dust Sample			
	Clay	B.R	M.A	Z-M
SiO ₂	57.55	0.77	0.42	0.31
TiO ₂	0.3	0.01	0	0
Al ₂ O ₃	15.84	0.24	0.07	0.04
Fe ₂ O ₃	3.32	0.05	0	0.03
MnO	0.04	0	0	0
MgO	2.35	0.94	0.24	0.3
CaO	6.77	54.08	55.65	55.07
Na ₂ O	1.39	0.39	0.36	0.29
K ₂ O	1.59	0.02	0.01	0.01
P ₂ O ₅	0.12	0.01	0.03	0.02
LOI	10.73	43.49	43.23	43.93

B.R: Buneer, M.A: Mohmand Agency, Z-M : Ziarat-Mullagori Mix

The grain size distribution curves for each marble dust and clay sample consist of both sieve analysis and hydrometer tests as per ASTM procedures (ASTM D4221) [18]. For the Mohmand agency region's marble dust, 76% are of silt size, 21% are of clay size, and 3 % are of sand size. For the marble dust of Buneer region, 79% are of silt size, 20% are of clay size, and 1% are of sand. The sample contains marble dust of two different (mix) regions; 82% are of silt size, 17% are of clay size, and 1% are of sand. For all three different types of marble samples, it can be indicated that these samples can be classified as silt-clay like material. Similarly, the gradation analysis was also performed for the clay sample. 71% of the grain size distribution are of sand size, 25% are of silt size, and 4% are of clay size. The grain size distribution curves are shown in Figure 5.

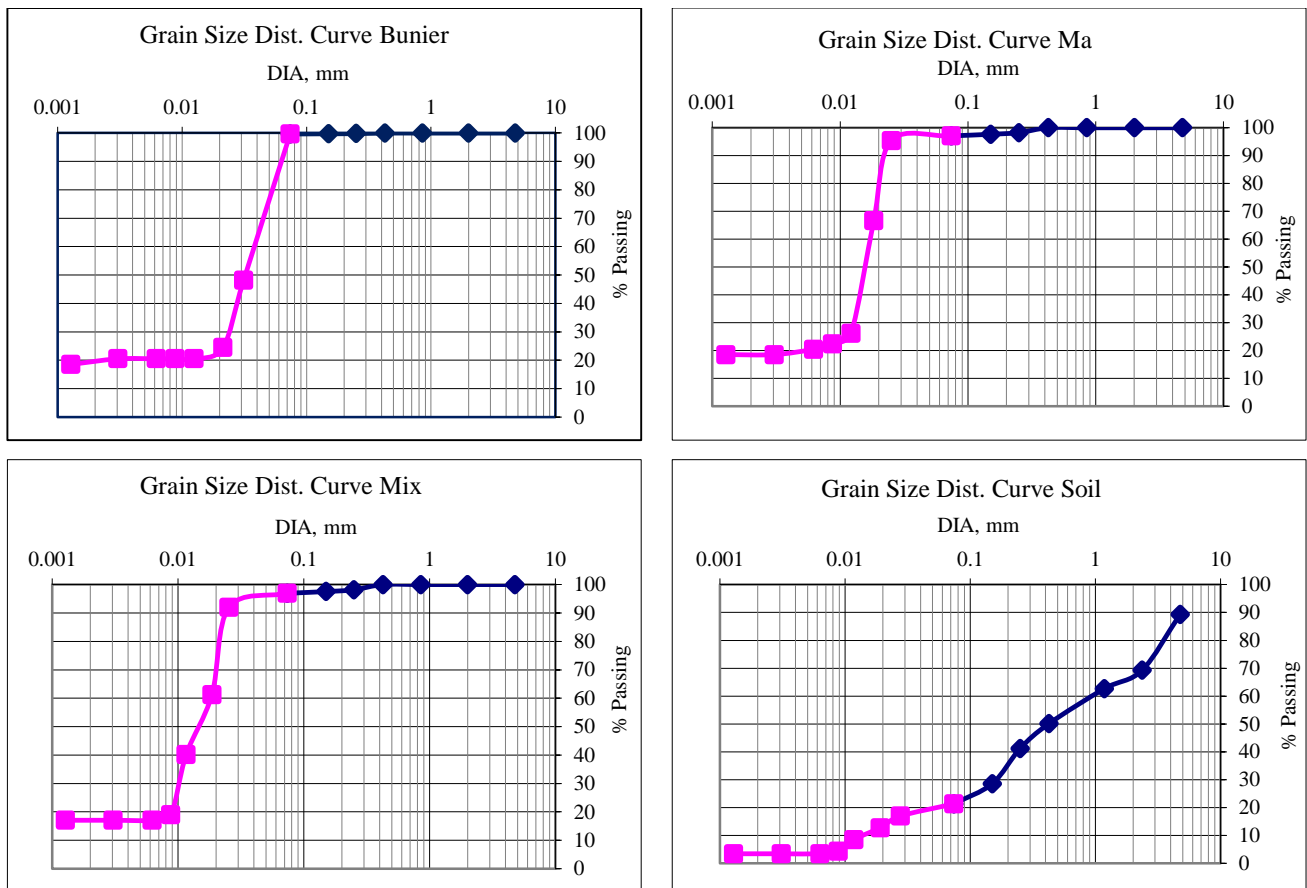


Figure 5. Grain size distribution curves for clay and marble dust samples

3. Mix Proportions and Test Methods

The bricks were prepared in a kiln located in Peshawar, Pakistan, by the kiln's standard methods. The percentages used were up to 30% at an amplification factor of 5% by weight for each marble dust sample source. Using a percentage range up to 30% was because of the literature, that high percentages if used would not improve any property of the prepared bricks. Twenty numbers of bricks were prepared for each source of marble dust sample, and the brick proportions are shown in Table 2.

Table 2. Proportions of brick samples

Bricks		Marble dust		Clay	
Brick sample	No. of bricks	%	Kg	%	Kg
A ₀	20	0	0	100	60
A	60	5	9	95	171
B	60	10	18	90	162
C	60	15	27	85	153
D	60	20	36	80	144
E	60	25	45	75	135
F	60	30	54	70	126



Figure 6. Proportions of marble dust and clay



Figure 7. Marble dust and clay in the mixed form set for making bricks



Figure 8. Molding of brick



Figure 9. measuring the temperature of the brick Kiln by infrared thermometer



Figure 10. Stacks of bricks for burning in a kiln

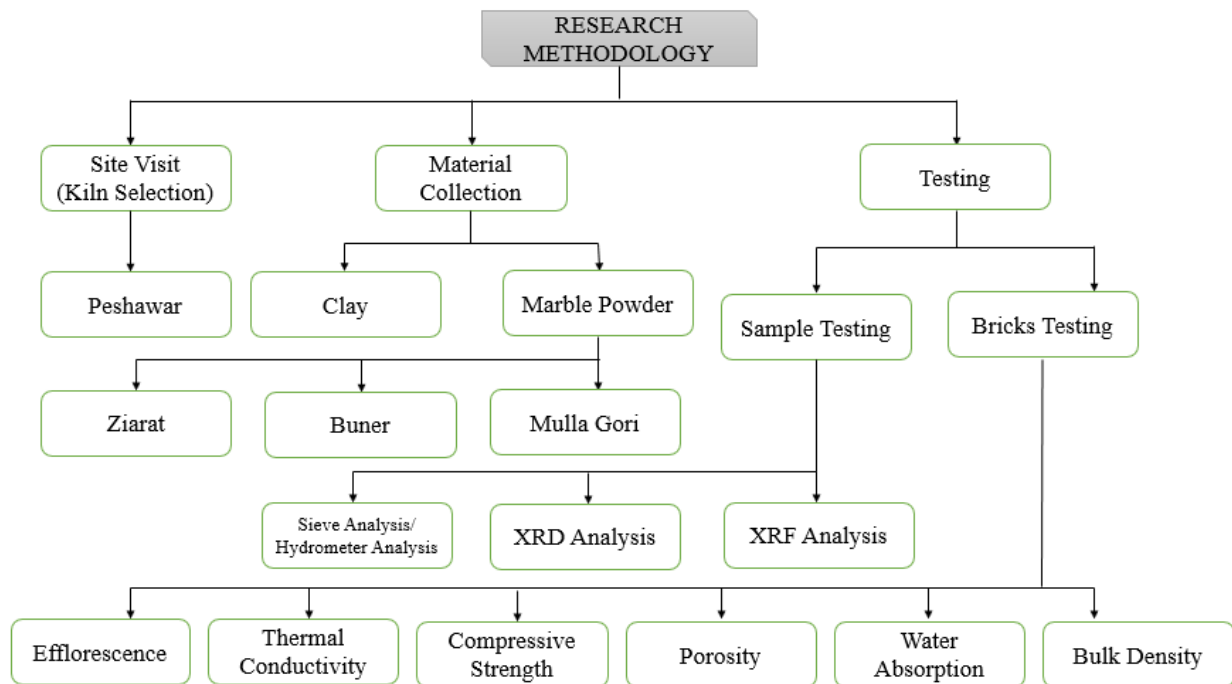


Figure 11. Research Methodology Flow Chart

The scope of the study was to determine the Bulk density, Porosity, Water absorption, Compressive Strength, Thermal Conductivity, U-Values, and Efflorescence tests on bricks according to ASTM standards (C20 and C67) [19, 20] and are shown in Figure 12 to 17.



Figure 12. Bricks in oven



Figure 13. Oven Dry Weight



Figure 14. Saturated bricks



Figure 15. Compressive Strength



Figure 16. Efflorescence Test

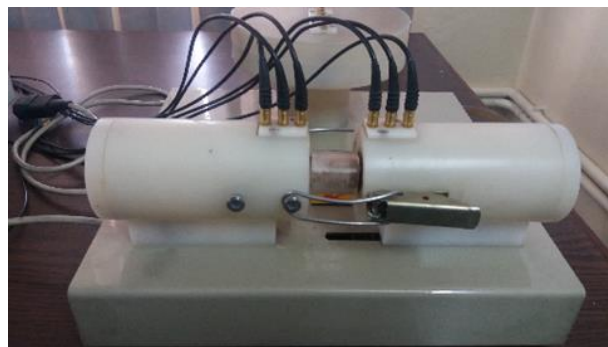


Figure 17. Thermal Conductivity

4. Results and Discussions

Table 1 shows that for three different samples of marble powder, CaO content is greater than 49%, and MgO content is less than 2.6%, indicating that all three samples are of calcite-type marble. The soil cast-off for bricks' preparation has SiO₂ and Al₂O₃ content greater than 49% and 15%, respectively, showing that the soil can be cast to produce fired ceramic material. The percentage of sintering components (MgO, Na₂O, and K₂O) is less, creating difficulty forming liquid phases at high firing temperatures.

Refer to Figure 4, calcite (CaCO₃) and quartz (SiO₂) are the main phases, and plagioclases (albite, anorthite) are minor phases in the marble dust. The clay contains quartz, clinocllore, illite/muscovite, and an insignificant quantity of calcite phases predominantly. Figure 5 demonstrates the grain size distribution for each marble dust sample and clay, comprising sieve analysis and hydrometer tests. For the marble dust of M.A, 76% are of silt size, 21% are of clay, and 3% are sand. And for the marble dust of B.R, 79% are of silt size, 20 % are of clay size, and 1% is of sand size. In the Z-M mix, 82% are of silt size, 17% are of clay size, and 1% are of sand size. For all three various types of marble samples, it can be indicated that these samples can be classified as silt-clay-like material [21].

Similarly, clay was also tested for gradation analysis. Hydrometer analysis was performed as it contained some fine particles. Figure 5 demonstrates that 71% of the grain size distribution is of sand size, 25% are of silt size, and 4% are of clay size. These properties show a close resemblance to that of the previous work done on the same subject. This is due to the chemical composition of marble dust samples of other countries close to Pakistan. The bricks were also backed by traditional methods in a kiln [22-25].

4.1. Properties of the Fired Clay Bricks

Different physical and mechanical properties of bricks were found and compared with the standard burnt clay bricks. The Bulk density, porosity, water absorption, compressive strength, thermal conductivity, U-values, and efflorescence of reference brick samples were 1.55 g/cm³, 12.6%, 16.93%, 18.06 MPa, 0.99 W/m.K, 3.92 W/m²K, and 0, respectively. All the properties are described in detail in the following section: The Bulk density values of bricks fluctuated from 1.55 to 1.27 g/cm³. This decrease in Bulk density is potential because of decomposed carbonates in the brick body. Figure 18 demonstrates the correlation between the Bulk densities of marble powder in various areas.

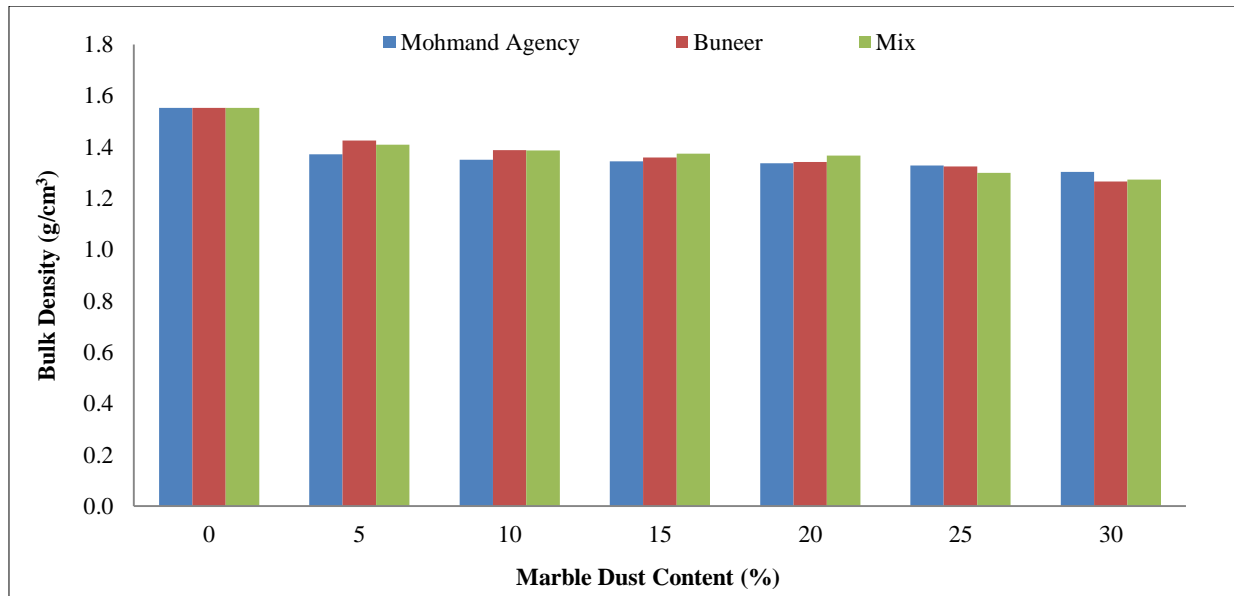


Figure 18. Comparison of Bulk density of marble dust samples

The porosity values of bricks fluctuated from 12.6 to 52.71 %. Such an increase in porosity is because of the release of CO₂ in the calcination of CaCO₃. CaO so formed in the decomposition of CaCO₃ is a high reactive constituent that can react with any material, developing new phases like calcium aluminosilicates. Moreover, CaO is an expandable material causing an increase in the brick porosity. Figure 19 demonstrates the correlation between the porosities of marble powder in different regions.

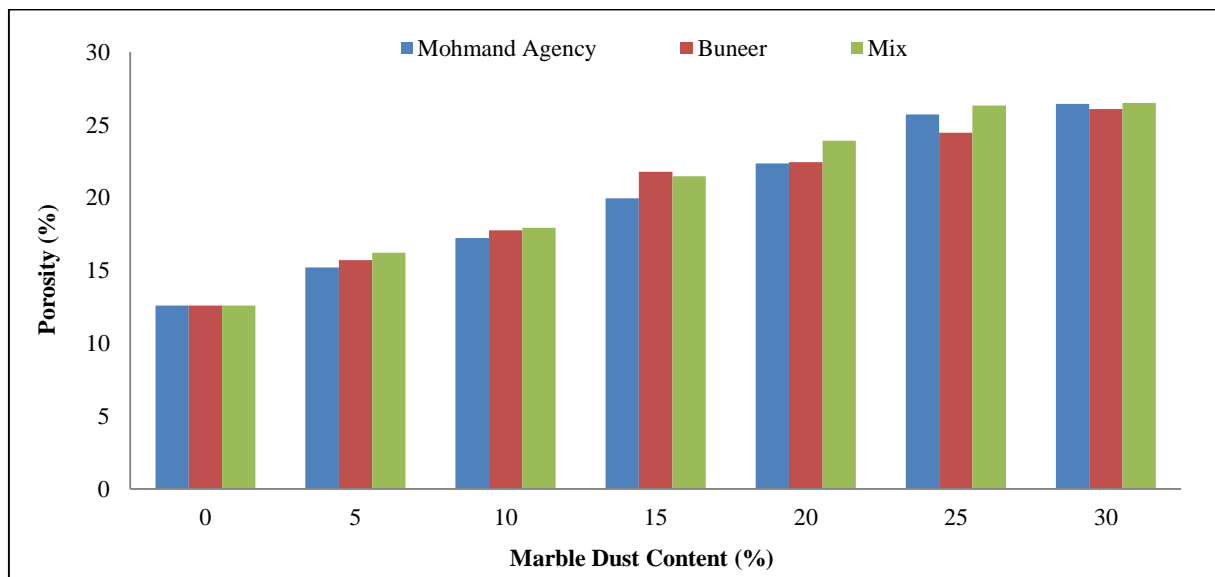


Figure 19. Comparison of Porosity of marble dust samples

The water absorption values of bricks fluctuated from 18 to 36.07%. This increase in water absorption is because of the increased porosity of produced bricks. Figure 20 demonstrates the correlation between the water absorption of marble powder in different regions.

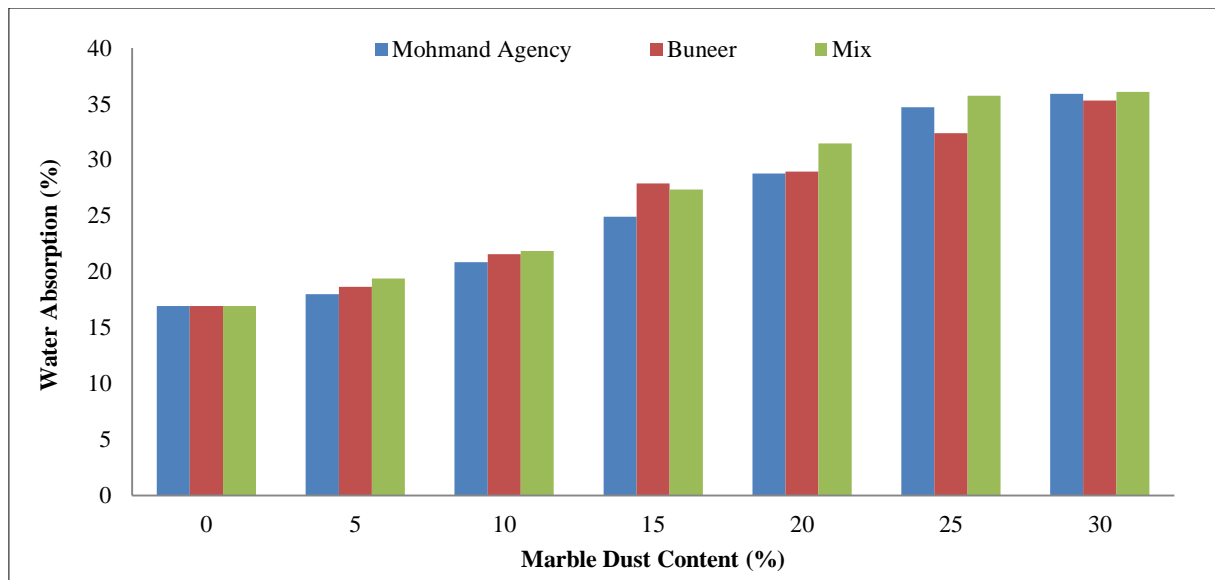


Figure 20. Comparison of Water Absorption of marble dust samples

The compressive strength values fluctuated from 18.06 MPa to 4.83 MPa. The loss in compressive strength is due to the increased porosity of produced bricks. Figure 21 demonstrates the comparison between the compressive strength of marble powder of different regions.

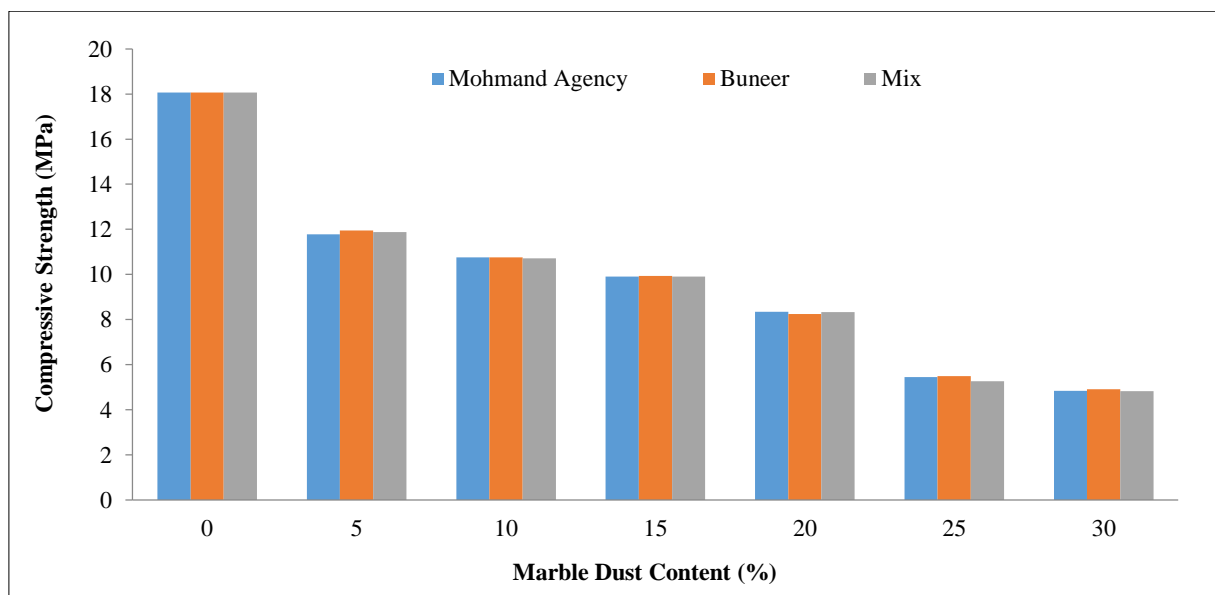


Figure 21. Comparison of Compressive Strength bulk density of marble dust samples

It is seen from the outcomes that by increasing weight in the percentage of marble powder, bricks' compressive strength decreases. These bricks can be used in areas where higher strength is not worrying, particularly in shelters for people of earthquake and flood-influenced places. There is no doubt that compressive strength is the most vital property of construction materials. The individual brick must have a base compressive strength of around 7 MPa as indicated by Turkish and corresponding European Standards (TS EN 771-1. Specifications for masonry units- part 1: clay masonry units 2005). The addition of marble powder up to 20% satisfies the requirements of compressive strength for individual bricks. The addition of marble powder up to 30% presents a maximum decrease of 4.83% compared to standard bricks.

The thermal conductivity values fluctuated from 0.99 to 0.86 W/mK. The decrease in thermal conductivity is due to the increased porosity of produced bricks. Figure 22 demonstrates the correlation between the thermal conductivity of marble powder in different regions. It is seen from the outcomes that by increasing weight in the percentage of marble powder, bricks' thermal conductivity decreased. These bricks can be used as helpful heat insulation construction material. The addition of marble powder up to 30% presents a maximum decrease of up to 13.35% compared to standard bricks.

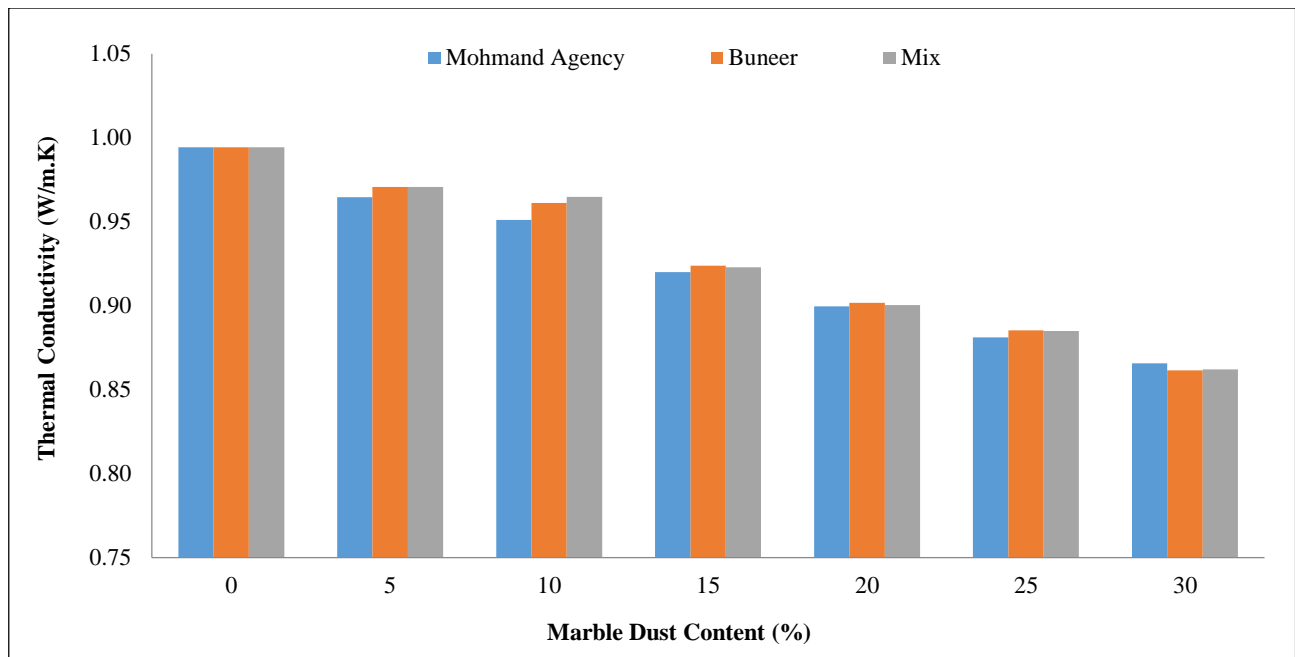


Figure 22. Comparison of Thermal Conductivity

The thermal performance is measured in terms of heat loss and is typically expressed in the construction industry as U-value. The U-values are used to quantify how effective the elements of building material are insulators, i.e., how effective they are at keeping heat from transmitting between and outside a building. The U-values varied from 3.92 to 3.44 W/m²K. This decrease in U-values is due to the increased porosity of produced bricks. Figure 23 demonstrates the correlation between the U-values of marble powder of different regions.

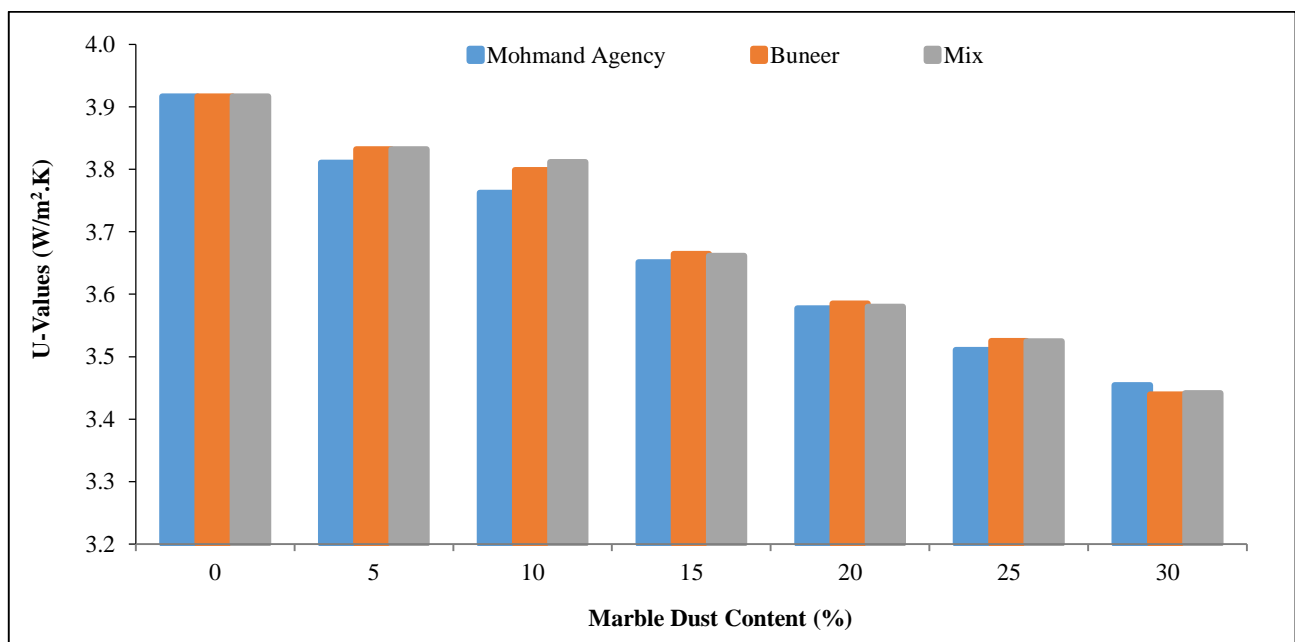


Figure 23. Comparison of U-Values

The efflorescence of every single set of bricks was tested according to standard procedure. The test results showed that there were no white patches seen on the bricks, demonstrating nil efflorescence. It was seen that there was an insignificant difference in each property of each sample. This is due to the same chemical compositions of all samples and were also fired at the same temperature.

Table 3. Comparison of this research effort with previous research studies

S. No	Reference	Firing Temperature (C°)	(%) Replacement	Property						
				Bulk density (g/cm ³)	Porosity (%)	Water absorption (%)	Compressive strength (MPa)	Thermal conductivity (W/mk)	U-values (W/m ² K)	Efflorescence
1	Sutcu, M. 2015	950	0-35	Decreased from 1.96 to 1.59	increased from 26 to 41.40	increased from 14 to 27.41	Decreased from 33.8 to 6.2	Decreased from 0.97 to 0.40	-	-
		1050	0-35	Decreased from 2.05 to 1.62	increased from 22.3 to 40.31	increased from 11 to 26.36	Decreased from 34.2 to 6.8	Decreased from 1.014 to 0.41	-	-
2	Halil Murat. 2007	-	0-30	Decreased from 2.05 to 1.62	-	increased from 12.4 to 19.02	Decreased from 24.9 to 7.2	-	-	-
3	Saboya 2006	750	0-20	Decreased from 1.64 to 1.62	-	increased from 22.08 to 25	-	-	-	-
		850	0-20	Decreased from 1.67 to 1.63	-	increased from 22 to 21.05	-	-	-	-
		950	0-20	Decreased from 1.72 to 1.62	-	increased from 21.08 to 23	-	-	-	-
4	Doumopolou. 2010	950	12.5,25 and 50	Decreased from 2 to 1.43	increased from 25 to 42.33	-	-	Decreased from 0.51 to 0.31	-	-
5	This Study.	1130	0-30	Decreased from 1.55 to 1.27	increased from 12.6 to 52.47	increased from 16.93 to 36.07	Decreased from 18.06 to 4.83	Decreased from 0.99 to 0.86	Decreased from 3.92 to 3.44	Nil

5. Conclusions

The results and findings of this research study led to the following conclusions and recommendations.

- The maximum decrease in Bulk density of marble waste bricks was 18.49% compared to standard clay bricks.
- By increasing the percentage of marble powder, porous bricks are produced. The maximum increase in porosity was 52.47% as compared to standard clay bricks.
- The water absorption of bricks is related to the quantity of marble dust. Therefore it was noticed that with the increase of the percentage of marble powder, the water absorption of bricks increases. The addition of marble powder up to 10% satisfies the requirements of water absorption for bricks. The maximum increase in water absorption was 53.06% as compared to standard clay bricks.
- The addition of marble powder up to 20% satisfies the requirements of compressive strength for individual bricks. Whereas the addition of powder up to 30% shows a maximum decrease of 4.83% compared to standard clay bricks.
- The addition of marble powder up to 30% resulted in a maximum decrease in thermal conductivity by 13.35% compared to standard clay bricks.
- No efflorescence has been observed in the marble dust bricks.
- The marble powder obtained from the three selected distinct regions demonstrated a similar pattern in the properties measured for the produced bricks.
- It is also concluded that the bricks produced by incorporating optimum replacement of marble dust can be used in parapet walls, roof tiles and partition walls, and other non-load bearing walls. These bricks can be used for insulation purpose in buildings as the thermal conductivity and U-values decreases by increasing marble dust content.

6. Declarations

6.1. Author Contributions

Conceptualization, Z.K., A.G., S.A.A.S., and K.S.; methodology, Z.K., A.G., K.S.; software, Z.K., A.G., S.A.A.S.; validation, Z.K., and N.W.; formal analysis, Z.K., A.G., S.A.A.S., Q.S., N.W., E.B., T.N., K.S.; investigation, Z.K.; resources, Z.K., A.G., K.S.; data curation, Z.K., A.G., S.A.A.S.; writing—original draft preparation, Z.K., S.A.A.S., T.N., K.S.; writing—review and editing, T.N., K.S.; visualization, Z.K., A.G., S.A.A.S., Q.S., N.W., E.B., T.N., K.S.; supervision, K.S.; project administration, E.B., T.N., K.S.; funding acquisition, K.S. All authors have read and agreed to the published version of the manuscript.

6.2. Data Availability Statement

Data sharing is not applicable to this article.

6.3. Funding

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6.4. Acknowledgements

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6.5. Conflicts of Interest

The authors declare no conflict of interest.

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