Green non-load bearing concrete blocks incorporating industrial wastes

Salman Ahmed¹ · Anwar Khatab¹ · Khalid Mehmood¹ · Seemab Tayyab¹

Received: 8 December 2019 / Accepted: 15 January 2020 / Published online: 24 January 2020
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Abstract

In this study, use of glass powder and marble powder as partial replacement of cement in various proportions (5%, 10%, and 15% by weight) in manufacturing of non-load bearing hollow concrete blocks is investigated. The manufactured blocks were evaluated for various characteristics as per ASTM C140/C140M, such as compressive strength, dry density and water absorption. Marble powder is obtained during sawing, cutting, shaping and polishing of marble, and it is normally rendered as solid waste. A huge quantity of discarded glass is dumped in landfills, world over. The mean dry densities of marble powder and glass powder used in this work are 2656.2 kg/m³ and 2547.4 kg/m³, respectively, making them lighter than ordinary cement. The optimum value is found to be 10% replacement of cement (by mass) by the waste materials. It is found that the compressive strength increases by 40% and 18%, dry density decreases by 4% and 5% and water absorption increases by 28% and 36%, if 10% cement is replaced by marble powder and glass powder, respectively. It can be concluded from the results that the non-load bearing hollow concrete blocks with improved compressive strength and light weight can be manufactured by using glass powder and marble powder. Recycling of solid wastes like marble powder and glass powder in concrete is advantageous: It will not only address the waste management issues, but will also result in saving the quantity of cement in concrete, which itself is environmentally hazardous material.

Keywords Concrete hollow blocks · Marble powder · Glass powder · Light weight · Strength

1 Introduction

Burnt clay brick is an ancient construction material used for building load bearing and partition walls. The bricks production by the widespread use of fresh clay has resulted in a serious shortfall of this natural material. Cement is the main constituent of all concrete materials that provides hardness and binds together the filler constituents. The raw materials of cement are limestone, sand, and clay [1].

The manufacturing process of cement at every stage of its production affects the environment in many ways.

The common problems are the emission of carbon dioxide and heavy metals in air and water pollution. Fine cement dust is a major pollutant, which harms people as well as plants in a very serious way. The workers of cement manufacturing factory have been observed affected by chronic diseases and respiratory disorders. Cement is alkaline in nature, which leads to skin and lungs diseases and liberates a huge amount of heat during curing, setting and hardening [2].

The dilemma has motivated some researchers toward the development of alternate building materials or

Salman Ahmed and Seemab Tayyab are the students (MSc and BSc respectively), and as per our institutional policy, official email addresses are not allotted to BSc and MSc students.

✉ Anwar Khatab, anwar.ce@must.edu.pk; anwar.khatab@yahoo.com; Salman Ahmed, salman.ahmed0092@gmail.com; Khalid Mehmood, khalid.ce@must.edu.pk; Seemab Tayyab, tayyabseemab14@gmail.com | ¹Department of Civil Engineering, Mirpur University of Science and Technology (MUST), Mirpur, AJ&K 10250, Pakistan.

SN Applied Sciences (2020) 2:266 | <https://doi.org/10.1007/s42452-020-2043-6>

replaces cement by waste materials obtained from different industrial and agricultural processes. Kim et al. have reported that the recycling of coal bottom ash in construction materials is one of the most encouraging alternatives to condense the environmental hazards associated with the safe dumping of coal bottom ash [3]. Adazabra et al. replaced fresh clay with spent shea waste: They have reported that spent shea waste can be used as an energy-contributing raw material in brick manufacturing [4]. Gencel et al. studied the effect of using waste marble powder aggregates in concrete paving blocks: They have reported high freeze–thaw durability and abrasive wear resistance with low mechanical strength [5]. Ahmed et al. used foundry sand and tile dust in place of sand in concrete pavements: They have reported cost-effective high strength finished products [6]. Senthamarai et al. have concluded that concrete with enhanced workability, compressive, tensile and flexural strengths and modulus of elasticity can be produced by recycling ceramic electrical insulator waste as coarse aggregates in lieu of conventional ones [7], [8]. Rana et al. studied the effect of using marble slurry as partial replacement of cement in concrete: They have reported that the mixes having 10% replacement of cement by marble slurry improve the transport properties of the concrete without compromising the mechanical strength. Additionally, the replacement produces much dense microstructure [9]. Jalil et al. studied the effect of industrial steel slag as partial replacement of cement in concrete: They have reported that the fine slag powder (passing sieve#200) could enhance the mechanical properties in comparison with the control specimens [10]. Munir et al. studied the effect of rice husk ash as partial replacement of cement in concrete: They have reported that RHA replacement (10–40% by cement weight) effectively suppresses the alkali–silica reaction expansion [11]. Dash et al. studied the effect of water cooled ferrochrome slag (WCFS) as fine aggregate (0–50%) on the properties of concrete: They concluded that up to 30% WCFS can be recycled with slight compromise over strength and no effect of concrete durability [12]. Yu et al. evaluated the performance of concrete made with steel slag and waste glass: They have concluded that the combination significantly enhances the fire resistance of the concrete [13].

Marble industry is one of the major waste generating units in Pakistan. Khyber Pakhtunkhwa Province of Pakistan has rich resources of marble and contributes to approximately 97% of the country's overall deposits. There are about 1500 marble processing units throughout the province. The development of marble tiles involves a considerable wastage of this expensive mineral, while quarrying, treating, and refining processes. About 50–60% of marble waste is produced around the globe during the

quarry operations, and it is largely being dumped in the pits, streets flooring, river bedsteads, grazing and agricultural fields, or junkyards: Fine powder of marble industry is one of the emerging environmental burdens [14]. Hence, the recycling of the waste material is very important.

Pakistan has a large glass industry, and it is reported that the production capacity ranges between 100 and 200 tons per day. Only the production of tableware stands at 30,000 tons per year. Just like other industrial wastes, a huge quantity of discarded glass is also being produced all over the world [15]. While the estimates for Pakistan are missing, it has been reported that about 1.3-pound glass waste per person is generated in neighboring India in a day [16]. The waste glass is disposed in empty lands or fields: This waste is highly unsustainable because it does not decay in atmosphere. Glass is mainly composed of quartz. Recycling of powdered waste glass in concrete as partial replacement of cement can be a viable solution toward the development of green, sustainable and economical buildings and roads.

Owing to environmental hazards caused by cement, waste marble and glass powder, the idea of recycling waste materials in place of cement in cementitious composites is highly beneficial. In this study, the use of glass powder (GP) and marble powder (MP) as replacement of cement in various proportions (5%, 10%, 15% by weight) in the manufacturing of non-load bearing hollow concrete blocks is carried out. The work intends to evaluate the potential of waste GP and MP for manufacturing green, and eco-friendly non-load bearing concrete hollow blocks. The performance of the blocks was checked through compressive strength, unit weight and water absorption as per ASTM C140/C140 M standards [17].

2 Materials and methods

The blocks were manufactured in factory situated at Sihala road Islamabad, the capital of Pakistan, under actual field situation. Type I Cement was obtained from a renowned local factory. Well-known Lawrencepur river sand and Margalla coarse aggregates (limestone) were used [18]. Ordinary potable water was used, and the wastes were obtained from local factories. The chemical compositions of the materials are described in Table 1 as follows:

It can be observed that cement has large fraction of silica along with oxides of aluminum, calcium, iron, magnesium and titanium. ASTM Type I Cement normally contains the percent of SiO_2 and Al_2O_3 in the range of 20 to 30% and 4 to 10%, respectively. Cement used in this study has SiO_2 and Al_2O_3 in the specified range. Cement has CaO more than 60%, and concentrations of Al_2O_3 , Fe_2O_3 and SiO_2 all are more than 3%.

Table 1 Chemical composition of cement, marble dust and glass powder (% by weight)

Oxide	Cement	Marble dust	Glass powder
SiO ₂	20.12	2.52	60.92
Al ₂ O ₃	5.53	0.71	1.29
Fe ₂ O ₃	3.47	0.26	–
CaO	62.2	53.7	4.12
MgO	1.71	1.02	2.79
SO ₃	1.63	0.08	–
Na ₂ O	–	0.56	5.19
K ₂ O	–	0.08	0.05
Specific gravity	3.14	2.68	2.55
Fineness (cm ² /g)	3310	5960	–
Loss on ignition	1.45	39.41	21.2

Fig. 1 XRD of marble powder

Glass powder is very rich in SiO₂ content along with oxides of aluminum, magnesium, iron and potassium in smaller quantities, whereas MP has low percentage of silica and high quantity of CaO. Loss of ignition for cement, MP and GP is 1.45, 39.1 and 21.20, respectively, at 1000 °C. LOI is low for cement compared to GP and MP. MP is obtained by cutting of marble rock (which is not pre-heated): It contains high amount of CaCO₃, which decomposes during heating at 750 °C and results in higher LOI [19].

The X-ray diffraction of GP and MP was recorded and is shown in Figs. 1 and 2, respectively.

The XRD pattern of marble powder indicates the presence of the crystalline phases of calcite (C), quartz (SiO₂), corundum (Co) with highest peak proportion of calcite, whereas glass powder comprises of quartz in excess with discrete presence of corundum. The XRD pattern reveals that the marble powder possesses crystalline nature and will not take part in secondary hydration. Rather, it will behave as a filler material.

The XRD spectrum of glass powder is amorphous in nature. Therefore, GP has the potential for taking part in secondary hydration and improving the microstructure and strength of the resulting concrete hollow blocks: This

Fig. 2 XRD of glass powder **Fig. 3** SEM image of marble powder particle

was also confirmed through a previous study conducted by Islam et al. [20].

The SEM image of marble powder particle is shown in Fig. 3. It can be seen that the particle has sharp edges and irregular shape. Sharp angles and rough texture are responsible for higher water absorption and lower workability. On the other hand, an irregular surface produces a stronger bond with the surrounding paste and leads to a higher strength.

Specimens were manufactured with 0%, 5%, 10% and 15% of glass powder and marble powder, respectively, as shown in Table 2. Total of 56 specimens with 8 specimens for each percentage replacement were prepared. The casting of hollow blocks is shown in Fig. 4.

Table 2 Composition of specimens

Specimen ID	C	GP5	GP10	GP15	MP5	MP10	MP15
Cement%	100	95	90	85	95	90	85
GP%	–	5	10	15	–	–	–
MP%	–	–	–	–	5	10	15
No of specimen	8	8	8	8	8	8	8

Fig. 4 Casting of hollow blocks **Fig. 5** Compressive strength

3 Results and discussion

The hollow concrete blocks $15 \times 20 \times 40$ cm in size were prepared by using the composition, shown in Table 2 as per standard methods. The manufactured hollow blocks were tested according to ASTM C-140 and C-140M test methods for compressive strength and water absorption [17]. The test results are summarized in Figs. 5 and 6.

Fig. 6 Water absorption test results

It is clear from the results that the strength of the non-load bearing hollow concrete blocks can be improved by the above-mentioned replacements. The 28 days compressive strength of the hollow concrete block without waste material is 5.55 MPa, and with the use of 5% and 10% marble powder as replacement of cement, the strength increases to 7.5 MPa and 7.8 MPa, respectively. The increase in strength is attributed to the rough texture of the powder particles. The rough texture results in higher mechanical bond with the surrounding cement matrix. The results are in close coordination with the previous studies, where the rough surface of the particles resulted in higher mechanical strength [21]. The finer particle size leads to a denser microstructure, which ultimately increases the strength. The filler effect of marble powder is also confirmed by Alyousef et al. while using it in self-compacting concrete [22]. Riaz et al. carried out a similar study, involving the use of a fine filler material in place of clay in fire-burnt clayey bricks: They have observed similar increase in compressive strength of the finished blocks [23].

However, by increasing the percentage of marble powder beyond 10%, i.e., 15%, the mean compressive strength is reduced to 6.8 MPa. The possible reason is the higher fineness of the marble powder as compared to cement particles as depicted in Table 1. The higher amount of marble powder increases the surface area of the fine particles resulting in enhanced demand of cement for bonding, which in turn reduces the compressive strength.

It is observed that with partial replacement of cement by glass powder in various proportions, 5% and 10%, the compressive strength increases to 6.2 MPa and 6.5 MPa, respectively. This increase is attributed to the pozzolanic nature of the powder and is also confirmed by Islam et al. [20]. However, with further increase in glass powder, i.e., 15%, the mean compressive strength comes back to 5.5 MPa: This indicates that higher amount increases the surface area of fine particles, demands more cement for bonding, which ultimately reduces the compressive strength. The results are in line with similar research reported by Kazmi et al. [24].

According to Building Code of Pakistan, minimum compressive strength for building brick should be 5 MPa [25]. Therefore, it can be concluded that even 15% of MP and GP can be effectively replaced with cement for sustainable block manufacturing leading to economical and green production.

Fig. 7 Variation of density with replacement

The control specimens have an average water absorption of 2.05%. When marble powder is added at 5%, the average water absorption of the specimens increases to 2.27% and as the percentage of powder is further increased to 10%, the water absorption reaches even higher value of 2.63%. The increased water absorption may be attributed to porous structure of the specimens. When glass powder is added at 5%, the water absorption reaches 2.64% and as the percentage of powder is increased to 10%, the water absorption increases to 2.8%. The higher water absorption may be attributed to enhanced porosity. Table 1 also demonstrates that cement is the densest of all the three materials, followed by MP and then GP. Higher density leads to lesser porosity. The presence of porosity was also confirmed by measuring the densities of all the manufactured specimens: It was observed that the specimens containing 15% MP and GP were 4–5% lighter than the control specimens. The variation of density as a function of replacement is shown in Fig. 7. It is evident from the results that the replacement results in lighter blocks as compared to the control ones. The density results are in close agreement with the results of water absorption in Fig. 6. The results are also confirmed by a previous study, conducted by Riaz et al., in which, a porous material resulted in lower densities and higher water absorption [26].

The SEM images of the specimens having 10% marble powder and glass powder are shown in Figs. 8 and 9, respectively, whereas that of the control specimen is shown in Fig. 10.

Figure 8 demonstrates a good dispersion of marble powder particles in the cement matrix and their strong attachment with the cement hydration products. This is attributed to the rough and irregular surface of the

Fig. 8 SEM image of specimens having 10% MP

Fig. 9 SEM image of specimens having 10% GP

Fig. 10 SEM image of control specimens

marble powder particles, as shown in Fig. 3. This is the reason for higher compressive strength in case of the specimens added with MP particles. The slight increase in strength in specimens added with GP may be attributed to later stage secondary hydration due to amorphous and siliceous nature of the particles. Figure 9 shows the formation of ettringite in the mix during the process of hydration. Figure 10 shows an excessive formation of ettringite in the control mix, due to a higher percentage of SO_3 in cement as given in Table 1. The sulfate compounds and gypsum react with calcium aluminate in cement: The reaction leads to the formation of ettringite: The primary formation of ettringite controls stiffening and is beneficial. The ettringite is uniformly dispersed throughout the cement paste as shown in

Fig. 10. Nevertheless, all the specimens have strength more than 5 MPa, a requirement for building blocks in Pakistan Building codes [26].

4 Conclusions

Based on the results of the experiments, it can be concluded that the non-load bearing hollow concrete blocks manufactured in this experimental program with marble powder and glass powder as replacement of cement ensure improvement, in terms of compressive strength and light weightness. On the basis of the experimental evidence, following conclusions are withdrawn:

1. The compressive strength increases by 40%, if 10% cement by weight is replaced by waste marble powder. The increase in strength is attributed to the rough texture of the marble particles. The rough texture increases mechanical bond with surrounding cement matrix.
2. Similarly, the compressive strength increases by 18%, if 10% cement by weight is replaced by glass powder. The increase in strength is attributed to the pozzolanic nature of the glass powder, which is highly siliceous and results in secondary hydration reactions.
3. The optimum value with regard to mechanical strength is 10% partial replacement of cement by the waste materials. Beyond that, the strength starts decreasing.
4. The water absorption, however, increases with increase in the amount of marble powder and glass powder. The water absorption increases by 28% and 36% with 10% partial replacement of cement by marble and glass powder, respectively. The increase in water absorption is attributed to the porous nature of the waste materials, which is also evident by lesser densities of the powders.
5. Glass and marble powders result in lesser densities of the finished products. The densities decrease by 4 to 5% of that of the control specimens for 10% replacement by glass powder and marble powder, respectively.

Acknowledgements This research was supported by the Office of Research Innovations and Commercialization (ORIC), Mirpur University of Science and Technology (MUST), Mirpur, AJ & K. We thank our colleagues from the department of Civil Engineering, who provided insight and expertise that greatly assisted the research.

Compliance with ethical standards

Conflict of interest The authors have no conflict of interest.

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