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Physical and mechanical properties of bricks with dust residue from marble in México. Physical and mechanical properties of the marble dust-residue from the Comarca Lagunera Province, in Mexico

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Abstract: The marble industry generates a large amount of dust waste.These wastes do not have a proper management plan, as well as being highly contaminating the population surrounding the site of the deposits for these materials.To offer a solution, this article shows the results of the development of a brick-based marble powder to achieve sufficient compressive strength for the construction of masonry walls in low-rise housing. The experimental program includes 16 different dosages that varies the amount of cement, lime, and sand, and keep constant the marble powder. The program includes the compressive tests for 160 bricks, compressive tests for 3 small walls, validated adherence under compression tests for 3 small walls, and absorption tests for 48 bricks.The results of the test showed that the compression strength of the individual bricks and wall is 4.0 MPa and 1.9 MPa, respectively, and the absorption of the bricks is 21% . These results of absorption, compression and adhesion are a first indicator of the feasibility of used these bricks for the construction of load-bearing walls in housing projects developed in areas of low seismic demands.

Key words: absorption; adhesion; compression; load-bearing walls; housing

1 Introduction

The purpose of this research is to find a use for the marble dust waste generated in the Comarca Lagunera region of Mexico, as the region currently produces 450 tons per day. This research is being conducted at the Autonomous University of Coahuila (Mexico), at the Torreón School of Architecture, because this is the area where the environmental problem exists and where research on alternative construction materials is being pursued. The project was developed in collaboration with the Structures and Seismic Research Group at the Nueva Granada Military University (Colombia).

The Lagunera region is a geographical area comprising 10 municipalities in the state of Durango and another 5 in the state of Coahuila, in Mexico. The state of Durango accounts for the largest share of marble extraction in Mexico. These two states process approximately 1,800,000 tons of marble per year, which is then sold worldwide (Ministry of Economy, 2016). From this production, companies generate 450 tons of marble dust waste daily, a byproduct of cutting and polishing the material. This marble dust spreads easily throughout the city due to constant air currents, exposing the entire population to respiratory diseases such as pneumoconiosis. This disease is considered one of the leading causes of death among marble workers (Ministry of Health, 2016). In addition to this environmental and health problem, the state of Coahuila is facing one of its most rapid economic declines, making it difficult for the population to purchase housing.

It is therefore important to find a prompt solution to the two problems mentioned: 1) finding a use for marble dust waste that would otherwise cause pollution from the production of masonry units, since only 62% of this dust is used in each unit, and 2) offering a low-cost housing solution to the city's residents living in poverty, through the production of masonry units for building walls. Although both problems may seem completely separate, they could share a single solution. For example, if the waste from the marble industry can be repurposed into an economical and durable building material, people in vulnerable situations will be able to improve the quality of their housing, and, with this, their health and quality of life.

The main objective of this research is to determine the appropriate mix ratio of aggregates, marble powder, cement, sand, and commercial masonry lime so that the bricks achieve sufficient compressive strength to construct masonry walls in low-rise housing.

This research addresses two questions: 1) Is it possible to manufacture masonry units using marble waste powder? and 2) Will units manufactured with marble waste powder achieve the compressive strength required for constructing walls in low-rise residential buildings (3.5 m)? Based on these questions, two hypotheses are proposed: i) it is possible to manufacture masonry units with a high content of marble waste powder if the correct procedure is followed, and ii) the manufactured units will achieve the minimum compressive strength required to construct masonry walls in low-rise residential buildings; in fact, the strength will be greater than that of some blocks currently sold in the region.

This article presents the results of two stages in the development of a marble powder brick for use in the construction of masonry walls in low-rise residential buildings. The first stage of the study's experimental program includes 16 different formulations, with the aim of determining the most suitable one for brick production; of these 16 formulations, 10 bricks were manufactured from each, resulting in 160 compressive strength tests on individual bricks, 3 compressive strength tests on small walls, 3 adhesion tests on small walls, and 48 water absorption tests on individual bricks. The tests were designed to verify that the bricks can perform adequately under compression in a wall of a low-rise residential building. With the formulation established, the second stage aims to eliminate brick curing and presents compression tests on 10 bricks that were cured by saturating them in water and 10 bricks that were not cured.

The first stage includes mixtures with different proportions of cement, lime, and sand, but without varying the amount of marble powder. The mixtures were designed to determine which one exhibits the best compressive strength performance. These experimental tests were conducted in accordance with the current Mexican Standards of the National Organization for Standardization and Certification of Construction and Building (NMX-ONNCCE).

1.1 Social issues

Housing is a basic necessity, given the human need for adequate shelter; however, for a large portion of the population in Coahuila who do not have steady employment, it is impossible to adequately meet this basic need, as their income is insufficient to purchase adequate housing, according to the National Survey of Household Income and Expenditure (ENIGH, 2016). In most cases, the only alternative for people with limited financial resources is to build their own homes; however, once built, these homes exhibit significant deficiencies, as they are most often constructed with inappropriate or low-strength materials (Salgado and Molar, 2017). People living in these homes are classified as living in asset poverty, since their income allows them to meet only certain needs, such as food or education, but not the possibility of acquiring a satisfactory home (López et al., 2012).

To estimate the number of homes built with fragile walls (walls made from urban waste materials, such as cardboard, paper, etc.), this study reviewed the results presented by the ENI-GH (2016). Thus, it was found that 62.2% of homes in poverty have fragile walls; therefore, it is necessary to propose a solution so that their inhabitants can have access to building low-cost masonry walls.

During the process of cutting and polishing a block of marble for decorative purposes, approximately 20% to 30% of the block is reduced to dust (Gencel et al., 2012), which highlights the large amount of waste generated in the region. The problem of marble dust waste is present worldwide; for example, Turkey is one of the countries with the highest annual marble production on the planet (Bilgin et al., 2012); this country also faces a massive problem with the management of waste from this industry. Another country facing marble waste issues is Egypt, which ranks among the leading marble producers (El-Sayed et al., 2016), and also struggles with storing waste material in the vicinity of production plants, thereby causing pollution for the local population nearby. By raising awareness of this issue, many researchers worldwide are seeking new uses and applications for the various waste products generated during marble processing.

1.2 Previous studies on marble dust

In 2012, Santos et al. attempted to manufacture a brick based on marble dust. The dosages proposed in their study were determined through trial and error, as there were no experimental references available to guide the brick manufacturing process. The compressive strength of the bricks in the study by Santos et al. (2012) was < 4.9 MPa. These bricks are classified as non-structural bricks, since the minimum compressive strength value for solid bricks used in structural applications with lengths < 300 mm is 6.9 MPa, according to Mexican Construction Industry Standard 404 of the National Organization for Standardization and Certification in Construction and Building (NMX-C-404-ONNCCE-2012); however, standard NMX-C-441-ONNCCE-2013 establishes that the minimum compressive strength for non-structural bricks is 3.1 MPa.

In 2014, Rangel and Nevarez attempted to determine the necessary mix proportions for manufacturing a structural brick using marble waste powder. They studied marble powder from three marble producers in the Lagunera Province region. Their study (2014) included mix proportions containing river sand, water, and gray cement. The specimens were tested for compressive strength at 7, 14, and 28 days after curing in water; they also constructed specimens with various percentages of cement in the mixture. The specimens containing 12% and 15% cement achieved the highest compressive strength values: for example, the compressive strength of these specimens was >10.78 MPa, which exceeds the minimum value required by the NMX-C-404-ONNCCE2012 standard for solid bricks for structural use. Rangel and Nevarez (2014) observed, on the other hand, that only the bricks manufactured with dust from one of the companies under study met the compressive strength limits. The comparison of the compressive strength results of bricks from different marble producers revealed strength differences of approximately 50%. The reason for these differences is that most facilities specializing in marble processing recycle water for multiple uses; the recycling process involves separating the water from the dust to through wastewater filtration. This has prevented the dust from becoming contaminated with other materials that affect compressive strength. Filtration involves separating the water from the dust using a natural trap. The method used by the company involves depositing the waste from cutting and polishing (water and marble dust) into a large pit, which also allows for the separation of the elements by gravity; since it is heavier, the marble dust sinks to the bottom of the pit and the water remains on top, allowing all the dust to separate from the water so it can be reused. When the waste containing water and marble dust is deposited in these pits, the greater weight of the marble dust causes it to sink to the bottom of the pit. With this separation, the water can be easily extracted to prevent the marble dust from containing chemicals that cause a loss of compressive strength in the bricks. In this study, only marble dust waste from the company that does not add chemicals to the water for reuse was used.

Santos et al. (2012) found that the chemical composition of the marble dust studied in their research has certain special characteristics, as shown in Table 1. It is observed that the majority of its composition is calcium carbonate, but it also contains, in smaller quantities, iron, aluminum, and silicon dioxide. Meanwhile, Shahul and Sekar (2009) found that the majority of the chemical composition of marble slurry is silicon oxide, with smaller amounts of iron oxide, magnesium oxide, sodium oxide, potassium oxide, aluminum oxide, and calcium oxide.

Table 1. Chemical composition of marble powder. Source: Santos et al. (2012). CC BY-NC-SA

Component	$CaCO_3$	Fe	Al	SiO_2
Content	95%	0.038%	0.10%	1.02%

2 Methodology

2.1 Experimental program

The experimental program in the first phase of this study includes 160 compressive strength tests on individual bricks measuring 50 × 80 × 230 mm, as well as 3 compressive strength tests on small walls, 3 bond strength tests on small walls, and 48 water absorption tests on individual specimens. The experimental program includes 16 mixtures with different proportions of cement, lime, and sand, but without varying the amount of marble powder.

2.2 Test mix proportion

For each mix, 10 specimens were cast. Some of the mixtures replace percentages of cement with lime, and others replace river sand with crushed limestone sand; this is to stop using river sand and preserve natural rivers, as mentioned by Singh et al. (2017). Once the appropriate mix ratio is found, in the second stage, 20 more bricks are manufactured to verify whether curing can be eliminated from the manufacturing process.

2.3 Dimensions of the specimens

The proposed dimensions are based on the findings reported by Betancourt et al. (2015), who note that neither the shape nor the dimensions affect the compressive strength of concrete containing marble powder. Wood was used for the molds used to manufacture the bricks, as it facilitates demolding and handling of the mold.

2.4 Test matrix

The mix designs proposed in this study were based on the cement percentages used by Rangel and Nevarez (2004), who considered 12% and 15% cement; These percentages are used with the aim of having the highest amount of marble waste powder in the mixture and, consequently, ensuring that the brick consists of 62% marble waste powder, despite the results of the studies by Santos et al. (2012), Bilgin et al. (2012), and Corinaldesi, Moriconi, and Naik (2010) demonstrated that replacing more than 10% of the cement with marble powder affects the compressive and flexural strength of concrete; Singh, Srivastava, and Bhunia (2017) and Singh, Choudhary, Srivastava, Singh, and Bhunia et al. (2017) also found that up to 15% of cement can be replaced with marble powder residue without reducing compressive strength.

In the 16 mixtures, the amounts of cement, lime, and sand were modified while keeping the amount of marble powder constant. First, the amounts of cement were adjusted to use the smallest possible amount of this material. River sand was replaced with crushed limestone sand, as river sand is scarce in the study region. Masonry lime was added to verify local practices and to assess the benefits or harm caused by this product when combined with cement.

Tables 2 and 3 show the dosages used in the mixtures containing 12% and 15% cement, respectively. For each mix design, 10 samples were prepared, of which 3 were tested after 7 days; another 3 after 14 days; and 3 more after 28 days, with one sample retained as a control. In all cases, the control sample was also tested as part of the specimens.

The percentages of lime in the mixtures were calculated based on the amount of cement added. The values for the other materials were calculated based on the amount of marble powder in the mixture. Thus, as shown in Tables 2 and 3, the 160 specimens produced in the study are included.

In the mix proportions of the research, the two cement percentages (12% and 15%) were tested to determine whether it is possible to reduce the amount of cement required for the brick to achieve the minimum compressive strength necessary to be classified as a structural brick. In general, the objective of these mix designs was to achieve the compressive strength of 6.9 MPa specified by the NMX-C-404 (2012) standard for solid structural bricks with lengths < 300 mm.

To produce the bricks, the mixture was prepared with the aggregates in a dry state; the quantities were as indicated in Tables 2 and 3, they were mixed, and finally, water was added until the mixture had the appropriate consistency to be placed in the molds.

The molds were filled with the mixture in two layers: a layer approximately half the height was placed, and the mixture was tapped four to five times around the mold; the same procedure was followed for the second layer, which was then leveled without any compaction.

Table 2. Mixtures with 12% cement. Source: own elaboration (2018).

Lot No	Marble dust	Sand	Water	Cement	Lime
1		20% (river)		12.00%	-
2		20% (crushed)	35%	12.00%	-
3		20% (river)		11.40%	5%
4		20% (crushed)		11.40%	5%
5	15 kg	20% (river)		10.80%	10%
6		20% (crushed)	20%*	10.80%	10%
7		20% (river)		10.20%	15%
8		20% (crushed)		10.20%	15%

Table 3. Mixtures with 15% cement. Source: own elaboration (2018).

Lot No	Marble dust	Sand	Water	Cement	Lime
9		20% (river)		15.00%	-
10		20%(crushed)		15.00%	-
11		20% (river)		14.24%	5%
12	15 kg	20%(crushed)	20%	14.24%	5%
13		20% (river)		13.50%	10%
14		20%(crushed)		13.50%	10%
15		20% (river)		12.74%	15%
16		20%(crushed)		12.74%	15%

3 Results

3.1 Brick production

The marble powder extracted from the storage site contains some residues, such as debris or lumps; the latter are formed by moisture in the air or by the rain. For this reason, it was necessary to screen the material through a No. 40 mesh

(0.42 mm) to separate out the marble chunks, lumps, and debris. The marble chunks and debris must be removed from the material, but the lumps can be crushed to turn them back into powder. Like the marble powder, the river sand must also be sieved, but using a No. 4 mesh (4.76 mm) to remove any stones or debris it may contain. Once the materials meet the required cleanliness and size specifications, the marble powder, sand, and cement are dry-mixed to achieve a homogeneous mixture of aggregates. Once the materials have been mixed dry, water is added. The first amount of water should be the as specified in each mix design, and then a little more water is added, depending on the mixture′s consistency, so that it can settle into the formwork and produce solid blocks. In the case under study, the initial amount of water—set at 20% or 35% in the mix design—was insufficient, so an additional 5% of water was added.

A release agent was applied to the formwork to prevent the bricks from sticking to it when removed from the mold. In this case, used motor oil was applied to the molds to facilitate the removal of the bricks from the molds. In this study, this material was used because it is easy to obtain, is reused to avoid polluting the environment, and does not cause any adverse effects on the pieces, such as leaving them with an inappropriate color or odor, or causing them to lose their compressive strength.

Ten specimens were obtained from each mixture, identified as L1-M1 through L1-M10 (Lot 1, Samples 1 through 10, etc.). These specimens were saturated with water and cured for 7, 14, and 28 days before being tested for compressive strength. Figure 1 shows the 10 specimens with their respective nomenclature.

In the first stage, curing consisted of saturating the bricks in water, as this is the most common curing process. In the second stage, the goal is to eliminate curing based on the amount of water used; to verify if this is possible, 20 additional bricks are constructed using the mix design that yielded the best compressive performance among the 16 studied in the first stage. The 20 bricks will be divided into two groups; 10 bricks will be cured, and the other 10 will not, to compare their compressive strength and determine whether it is advisable to omit curing in the bricks.

3.2 Test description

For the compression test, it is necessary to allow the bricks to dry completely, since if they contain moisture, this helps the powder to compress under the load. In this way, the bricks might not fail, and thus high but unreliable results could be obtained; therefore, the bricks were left to dry in the open air for 24 hours prior to the compression test.

The absorption test for the bricks was conducted using the procedure specified in standard NMX-C-037-ONNCCE-2013. Accordingly, three brick specimens from each mix were used and saturated in water for 24 hours. The absorption capacity of the specimens was calculated using equation 1. This parameter allowed us to determine the percentage of water absorbed by each brick:

$$H\%=\frac{p\mathrm{h}-ps}{ps}\times 100 \tag{1}$$

Where H is the percentage of moisture that absorbs the specimen, and ph and ps are the weights of the wet and dry specimens, respectively.

Adhesion tests between bricks were included in the study because it was observed that some bricks had a very smooth contact surface, which could result in these bricks failing to adhere to one another and, therefore, failing to achieve adequate compressive strength. The adhesion tests between bricks were conducted in accordance with the guidelines of standard NMX-C-082-ONNCCE-2013. The samples used for the adhesion tests between bricks are the same as those corresponding to the three walls constructed to determine the compressive strength of the walls.

The low walls were constructed using uncured bricks; in this regard, the guidelines of the Complementary Technical Standards for Masonry of the Federal District (Official Gazette of the Federal District, 2004) were followed. The low walls consist of three bricks, to which a vertical load was applied to determine compressive strength. The mortar used to join the bricks was cured, and sufficient time was allowed for the mortar to reach an adequate compressive strength of 8.5 MPa.

A 6-mm nozzle was used in the construction of the low walls. This is in accordance with the recommendations reported by Salais and Ponce (2015). The 1:4 cement-to-sand mortar mix ratio used is in accordance with the recommendation by Arrañaga et al. (2016), which specifies the ratio that achieves a compressive strength of 8.5 MPa.

3.3 Test results

Figure 2 shows the variation in the compressive strength of the bricks at 7, 14, and 28 days of age for the 16 mix designs. To determine the strength, a contact area of 18,400 mm² was considered during load application. Figure 2 shows that the compressive strength at 7 days is highest in mix 7, which contains river sand, 10.2% cement, and 15% lime. At 14 days, mix 7 exhibited the highest compressive strength. Finally, at 28 days, mix designs 12 and 16 exhibited the highest compressive strength. The amount of cement in mix 12 is 1.5% greater than the amount of cement in mix 16. The compressive strength results shown in Figure 2 indicate that compressive strength increases rapidly between 0 and 7 days of age, reaching approximately 82% of the maximum strength, while between the 7 and 14 days, the increase in compressive strength is small: approximately 15% of its strength, and between 14 and 28 days, the increase is even smaller: approximately 3%. The test was conducted in accordance with NMX-C-036-ONNCCE-2013.

Figure 1. Specimen samples from batch 1. Source: own work (2018). CC BY-NC-SA

The difference in compressive strength between 14 and 28 days is 0.06 MPa; therefore, the strength at 14 days can be considered acceptable, and testing at 28 days can be omitted. Kore and Vyas (2016) found that the compressive strength at 28 days of specimens containing marble slurry varied by 18% compared to samples without it; these authors argued that the presence of marble powder does not significantly affect the increase in strength at 28 days. Table 4 shows the average results of the compression test batches at 7, 14, and 28 days of specimen age, as well as the standard deviation and coefficient of variation of the results. The first column of the table indicates the sample group, which in this case corresponds to the 16 tested mix proportions. The following three columns contain the data at 7 days of age for the samples, including the average compressive strength, which is 2.53 MPa, as well as the standard deviation, which is 0.79 MPa, and the coefficient of variation, which is 31.3%, respectively.

Table 4 shows that the bricks have low compressive strength due to the amount of marble powder; according to Santos et al. (2012), Bilgin et al. (2012), and Corinaldesi et al. (2010).

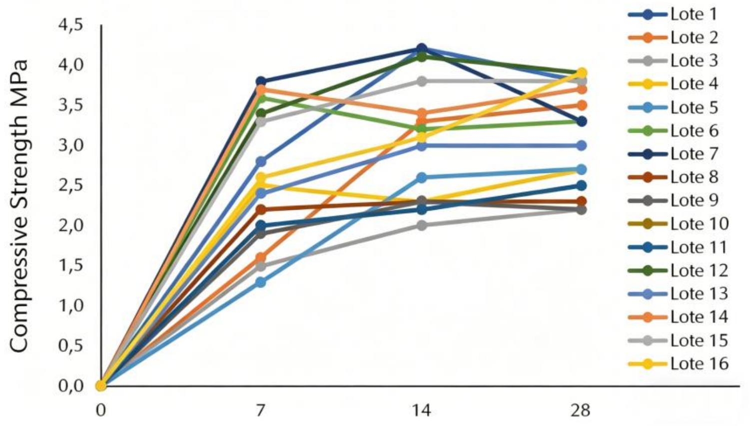

Figure 2. Variation in the compressive strength of bricks as curing days increase. Source: own work (2018).

Table 4. Average compressive strength, standard deviation, and C.V. Source: own elaboration (2018).

Group	Day 7			Day 14			Day 28		
	Average, MPa	σ	C.V. (%)	Average, MPa	σ	C.V. (%)	Average, MPa	σ	C.V. (%)
1	2.53	0.79	31.3	3.01	0.74	24.80	3.07	0.62	20.5

The absorption tests showed that the average water absorption value is 21% and that the coefficient of variation is 7.7%. This absorption value is higher than the limit value of 19% indicated by the standard NMX-C-037-ONNCCE-2013. This is due to the amount of marble powder in the bricks, because calcium oxide (CaO) is very reactive and upon contact with water forms calcium hydroxide ($Ca(OH)_2$) (Bilgin et al., 2012), which generates porosity in the bricks and, consequently, higher absorption; therefore, the bricks do not comply with the absorption limit value, and the moisture absorption of the bricks must be improved. It is worth mentioning that the absorption found coincides with the results obtained by Bilgin et al. (2012), which show that adding 70% marble powder to concrete to manufacture bricks results in absorption between 30% and 40%; therefore, it can be said that if marble powder is increased in a mixture, absorption also increases.

Figure 3 shows the compression test of one of the low walls. These tests on the low walls revealed that the average compressive strength is 1.9 MPa, with a coefficient of variation of 15.3%. The same figure shows how the specimen holds the bricks together with mortar, which demonstrates that there is good adhesion between them to withstand compression. To construct the low walls, it was necessary to dampen the bricks: if the bricks are not dampened, there is insufficient adhesion between them when joined with mortar.

Based on the results of the compression tests, this study considers that mix 16 is the one with the best performance, considering that this mix has the lowest amount of cement and contains crushed sand, in addition to showing an increasing trend in the compression test results. Using mix 16, 20 additional bricks were manufactured, divided into two groups of 10 pieces. One group of 10 bricks was cured using the procedures recommended by the NMX-C-148-ONNCCE2007 standard. The second group of 10 bricks was not subjected to any type of curing. In this study, compression tests were performed on both cured and uncured bricks. The two new batches of 10 bricks were tested for compressive strength at 7 and 14 days, considering that in the 16 mixtures tested during the previous stage, no significant increases in compressive strength were observed between the tests at 14 and 28 days of age.

Table 5 shows the average compressive strength values for cured and uncured bricks. In Table 5, Group 1 corresponds to cured bricks, and Group 2 to uncured bricks. The table shows that after 14 days, there is a 20% difference between cured and uncured bricks. This difference indicates that curing is not necessary to achieve higher compressive strength in the bricks, as a strength of 3.1 MPa is sufficient for compressive loads in low-rise residential walls.

Figure 2. Brick masonry panels. Source: own elaboration (2018). CC BY-NC-SA

Table 5. Mean compressive strength value. Source: own elaboration (2018). CC BY-NC-SA

Group	Day 7		Day 14	
	Average, MPa	C.V. (%)	Average, MPa	C.V. (%)
1	2.6	12	3.1	14
2	2.6	14	2.5	16

4 Discussion

The compressive strengths obtained with values lower than those required by the standard are due to the amount of marble powder contained in the specimen, as noted by Singh et al. (2017) and Santos et al. (2012): as the amount of marble powder increases, the compressive strength decreases; therefore, the values reported by Singh et al. (2017) and Santos et al. (2012) recommend replacing are those of 10% marble powder by cement, so that compressive strength is not affected.

For the present study, a percentage of 62% marble powder was used, which is higher than that recommended by Singh et al. (2017) and Santos et al. (2012), a factor that affects compressive strength; therefore, in order for the bricks to achieve the 6.9 MPa specified by the Mexican Standard (NMX-C-404ONNCCE-2012) for structural bricks, further testing of mix proportions or the development of suitable manufacturing techniques to achieve this value is necessary.

The manufacture of bricks made from marble powder is feasible, as noted by Betancourt et al. (2015) and Rangel and Nevarez (2014); since the bricks do not undergo a firing process, their environmental impact is reduced. Bilgin et al. (2012) note that adding marble powder to bricks helps reduce costs, as it utilizes a waste material, while simultaneously supporting environmental sustainability. Gencel et al. (2012) conclude that the blocks they manufacture using marble powder exhibit better resistance to abrasive wear.

In this study, the appropriate technique for manufacturing the bricks was successfully defined. In addition, an optimal mix ratio was determined to ensure the bricks achieve the compressive strength required for non-structural elements according to the standard. The correct method for mixing the materials was also identified, and finally, a mold was fabricated to ensure the bricks have the correct appearance without being damaged. Based on the above, it is possible to construct masonry walls in low-rise residential buildings as non-structural elements.

5 Conclusion

The experimental results reported in this article demonstrate that it is feasible to produce bricks made from marble waste powder for constructing masonry walls in low-rise residential buildings, up to 3.5 m in height, in areas with low seismic risk.

In this study, we were able to determine the mix design with the best compressive strength and bond strength, as well as the most cost-effective mix by replacing cement with commercial masonry lime.

The mix that yields good results for brick manufacturing is mix number 16, which consists of 12.74% cement and 15% lime. This allows for the use of marble dust, thereby reducing pollution caused by the accumulation of this material outdoors.

Regarding water absorption, the result obtained is 21%, which is 2% higher than the maximum allowed by the standard, which is 19%. Water absorption in the bricks affects the moisture lost by the mortar they are joined. This effect is mitigated by applying water to the bricks before bonding them with mortar. If the bricks are not moistened, they absorb all the moisture from the mortar, which results in a loss of adhesion due to moisture loss. Moistening the bricks also helps remove any dust they may have, and removing this dust results in better adhesion. Based on the adhesion achieved, it is concluded that it is sufficient between the pieces for them to work under compression, without adding any modifications to the brick or the mortar.

Curing can be omitted in the brick-making process, as the difference in strength between cured and uncured bricks is 20%, and this increase is considered negligible.

The vertical compression test results for low walls show values of 1.9 MPa, which are considered acceptable for use in residential walls, as this material is more suitable than those currently in use (urban waste).

In the tested mix designs, it was observed that the mixtures with the highest compressive strength values are those containing crushed limestone sand rather than river sand.

Another advantage of mix design 16, chosen as the most suitable, is that it achieves the required compressive strength with a lower amount of cement compared to mix design 12.

The low compressive strength values indicate that further study is needed to determine mix designs that can achieve the compressive strength of 6.9 MPa specified by the Mexican standard (NMX-C-404ONNCCE-2012). To modify the mix designs, chemical and physical studies of the materials must be conducted to determine the appropriate aggregate mix design for achieving the required compressive strength in structural bricks.

Once the correct mix design and the compressive strength of structural elements have been defined, tests must be conducted to determine the properties of the materials, such as tensile strength, modulus of elasticity, and life cycle analysis.

Finally, future studies aim to construct masonry walls in a 1:1 scale low-rise dwelling and validate the results obtained in this research.

Conflicts of interest

The author declares no conflicts of interest regarding the publication of this paper.

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