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

Propiedades físicas y mecánicas del polvo-residuo de mármol de la provincia de la Comarca Lagunera, en México

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Abstract

The marble industry generates a lot of waste powder. This waste lacks an adequate management plan, besides being highly contaminating for the population surrounding the site of the deposits of these materials. In order to offer a solution, this article presents the results of the development of a brick based on marble dust, which has sufficient compressive strength to build masonry walls in low-rise housing. The experimental program includes 16 different dosages, in which the amount of cement, commercial masonry lime and sand are varied, and the amount of marble dust is left constant. The program includes the compression test of 160 bricks, three compression tests on walls, three tests of validated adhesion to compression on walls and 48 absorption tests. The results of the tests showed that the compressive strength of the individual pieces and of the walls is 4.0 MPa and 1.9 MPa, respectively, and the absorption of the pieces is 21%. These results of absorption, compression and adhesion are the first indication of the viability of the use of these bricks for the construction of load-bearing walls in housing developed in areas of low seismic threat.

Keywords: Absorption, adhesion, compression, load-bearing walls, housing;

Resumen

La industria del mármol genera gran cantidad de desperdicio en polvo. Estos desechos carecen de un adecuado plan de manejo, además de resultar altamente contaminantes para la población que rodea el lugar de los depósitos de dichos materiales. Para ofrecer una solución, en este artículo se presentan los resultados del desarrollo de un ladrillo a base del polvo de mármol, que tenga una resistencia a compresión suficiente para construir muros de mampostería en viviendas de baja altura. El programa experimental incluye 16 dosificaciones diferentes, en las que se varía la cantidad de cemento, cal comercial para albañilería y arena, y se deja constante la de polvo-residuo de mármol. El programa incluye el ensaye a compresión de 160 ladrillos, 3 ensayos a compresión en muretes, 3 pruebas de adherencia validada a compresión en muretes y 48 pruebas de absorción. Los resultados de los ensayos demostraron que la resistencia a compresión de las piezas individuales y de muretes es de 4,0 MPa y de 1,9 MPa, respectivamente, y la absorción de las piezas es del 21%. Estos resultados de absorción, compresión y adherencia son el primer indicativo de la viabilidad del uso de estos ladrillos para la construcción de muros de carga en viviendas desarrolladas en zonas de amenaza sísmica baja.

Palabras clave: Absorción; adherencia; compresión; muros de carga; vivienda;

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Introduction

The purpose of this research is to look for uses for waste marble dust that is generated in the Comarca Lagunera province, in México, since 450 t per day are generated in that region. This research is done by the *Universidad Autónoma de Coahuila* (México), and the *Escuela de Arquitectura Unidad Torreón*, considering that this is the region besieged by the environmental problem, and where research lines have been developed for alternative construction materials. The project has been elaborated in collaboration with the Structures and Seismic Research Group of the *Universidad Militar Nueva Granada*.

Lagunera province is a geographical region made up of 10 municipalities in Durango state, and other five in Coahuila state, in México. The State of Durango has the largest marble extraction in Mexico. These two states process approximately 1.800.000t/year, which is then commercialized all over the world (Secretaría de Economía, 2016). From this production, the companies generate daily 450 t of waste powder, which is the outcome of that material being cut and polished.

This marble dust spreads easily throughout the city thanks to the constant air currents, and it exposes citizens to respiratory illnesses such as pneumoconiosis, which is considered one of the main causes of death among marble workers (Secretaría de Salud, 2016). In addition to this environmental and health problem, the state of Coahuila is facing one of its most dizzying economic downturns, making it difficult for the population to purchase a home.

It is, then, important to look for a fast solution to the two aforementioned problems: 1) to give use to the waste marble dust which, otherwise, is generating contamination as of the fabrication of pieces of masonry, when only 62% of the said dust is used in each piece, and 2) to offer a low-cost housing solution for the city's poor inhabitants by generating masonry pieces to build up walls. Although the two problems may seem completely separate, they may share a solution. For example, if marble industry waste can be used to turn it into some economic and durable construction work, vulnerable persons could improve their living quarters' quality and thus, benefit their health and life standards.

The main purpose of this research is to look for the adequate dosage of aggregates (marble dust, cement, sand and commercial lime) so that the bricks reach resistance through adequate compression to build masonry walls in low-height housing.

For the development of this research, two questions are posed: 1) Can masonry pieces be fabricated using marble residue dust? and, 2) Will the pieces made of marble-residue dust reach resistance to the necessary compression to build walls in low-height housing (3,5 m)? Based on these questions, two hypotheses are proposed: i) It is possible to make masonry pieces with a high contents of marble residue dust if the adequate procedure is followed; and ii) the built pieces will reach the minimum resistance required under compression to build up masonry walls for low-height housing; even more so, resistance will be greater than the one borne by pieces presently merchandized in the region.

The article describes the results of two stages to develop a marble dust brick for the construction of masonry walls for low-height housing. The first stage of the study's experimental program includes 16 different dosages to define which is the most adequate for brick making. Out of these 16 dosages, 10 bricks are made to then have 160 trials of compression strenght in individual bricks; three trials under compression for walls; three wall adherence trials, and 48 absorption trials for individual bricks.

The trials were planned to find out whether the bricks can be adequately used under compression in a low height housing wall. With the established dosage, the second stage seeks to eliminate the curing of the bricks, and a trial is done with 10 bricks already cured by saturating them with water, and 10 bricks that were not cured.

The first stage includes mixtures of different cement, lime and sand dosages, but without varying the amount of marble dust. The mixtures were projected so as to verify which of them shows the best behavior through compression strenght. These experimental trials were carried out in compliance with the Mexican Norms of the National Organism for Construction and Edification Normalization and Certification (NMX-ONNCCE, for its Spanish acronym) in force.

Social issues

Housing is a basic condition because of the need humans have for appropriate sheltering; nonetheless, for most of Coahuila population who do not have a fixed job, it is impossible to adequately satisfy this essential need because their income is not enough to buy an adequate house, according to the National Survey on Homes' Income and Expenses (ENIGH, 2016).

In most cases, the sole alternative for the population with scarce economic resources is to build their own houses; however, once these homes are built, they show enormous deficiencies because most of the time they are made with inappropriate or weakly resistant materials (Salgado y Molar, 2017). People who live in such housing are known as those in patrimonial poverty, since their income allows them to satisfy only certain needs, such as food or education, but without the possibility of acquiring a satisfactory home (López et al., 2012).

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

During the process of cutting and polishing a block of marble for decorative purposes, approximately 20% to 30% of the block is turned into dust (Gencel et al., 2012), which is evidence of the large amount of waste generated in the region. The problem of marble dust disposal is present worldwide.

For example, Turkey is one of the countries with the highest annual production of marble on the planet (Bilgin et al., 2012); this country also has a huge problem with the waste management of such industry. Another country with marble waste problems is Egypt, which is among the major marble producers (El-Sayed et al., 2016), and also has the problem of storing the waste material around the production plants, thus generating pollution to the nearby population.

By creating awareness of this problem, many researchers internationally are looking for new uses and applications for the different waste products generated in the treatment of marble.

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Propiedades físicas y mecánicas del polvo-residuo de mármol de la provincia de la Comarca Lagunera, en México.

Preliminary studies on waste dust marble

In 2012 Santos et al., tried to manufacture a brick based on marble dust. The dosages proposed in their study were trial-and-error verified as there was no experimental reference to start brick making. Compression strenght for the Santos et al. brick study (2012) was < 4,9 MPa. These bricks are classified as non-structural bricks since the minimal value at resistance without compression for solid <300 mm long bricks for structural use is 6,9 MPa, in compliance with the Mexican Construction and Edification Industry 404 Norm by the National Organism for Construction and Edification Certification (NMX-C-404-ONNCCE-2012). Still, norm NMX-C-441-ONNCCE-2013 states that the minimum compression strenght for bricks for non-structural use is 3.1 MPa.

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 value of compression strenght for solid bricks for structural use with lengths < 300 mm is 6.9 MPa, according to the Mexican Standard of the Construction Industry 404 of the National Organism of Standardization and Certification of Construction and Building (NMX-C-404-ONNCCE-2012); however, the standard NMX-C-441-ONNCCE-2013 establishes that the minimum compression strenght for non-structural use bricks is 3.1 MPa.

In 2014 Rangel and Nevarez tried to set down the necessary dosages to make a structural brick with waste marble dust. They studied this dust from three producers in the Provincia Lagunera region. Their 2014 study included dosages that had river sand, water and grey cement. The specimens were tried for compression at 7, 14 and 28 days after being water cured; they also built specimens with various percentages of cement in the mixture. Specimens containing 12% and 15% cement reached the highest values of compressive strength; for example, the resistance of such specimens was > 10.78 MPa, which is higher than the minimum value required by the NMX-C-404-ONNCCE2012 standard for solid bricks for structural use.

They observed, on the other hand, that only the bricks made of dust from one of the enterprises participating in the study reached resistance limits under compression. The comparison of the results of compression strenght for the bricks from different marble producers showed a resistance difference of around 50%. The reason for such difference is that most of the companies specializing in marble treatment recycle water in order to give it more than one use; recycling consists of separating the water from the dust through residual water filtering.

This has prevented the dust getting contaminated by other materials affecting compression strenght. Filtering consists of separating water from dust by means of a natural trap. The method used by the company is to deposit the cutting and polishing leftover (water and marble dust) in a huge well so, in addition, element separation is reached through gravity since – as it is heavier – marble dust goes to the well bottom and water remains above, which allows the fine dust to separate from water so the latter may be used again.

When the waste material in the water and marble dust is placed in these wells, the heavier weight of marble dust takes it down to the bottom. With this separation, water can be extracted easily to prevent marble dust from having chemicals that may generate loss of compression strenght in the bricks. In this research marble residual dust was used from the company that does not add chemicals to the water so it can be reused.

Santos et al., (2012) found that the chemical composition of the marble dust – object of this study – has certain special characteristics, as can be seen in Table 1. It can be observed that most of the composition is calcium carbohydrate, but it also has, in a lesser amount, iron, aluminum and silica oxide, whereas Shahul and Sekar (2009) found that most of the chemical composition of the marble sludge is silica oxide and, in lesser amounts, iron oxide, magnesium oxide, sodium oxide, potassium oxide, aluminum oxide and calcium oxide.

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

Component	$CaCO_3$	Fe	Al	SiO2
Contents	95%	0,038%	0,10%	1,02%

Methodology

Experimental program

The experimental program at the first stage of this study includes 160 trials of compression strenght for individual 50 x 80 x 230 mm bricks, as well as 3 compression trials on small walls, 3 adherence trials on small walls, and 48 absorption trials for individual pieces. The experimental program includes 16 mixtures with different dosages of cement, lime and sand, but without variation in the amount of marble dust.

Trial dosages

For each dosage, 10 pieces were made. Some of the mixtures substitute cement percentages for lime, and others substitute river sand for ground lime sand; this in order to stop using river sand and preserve natural rivers, as mentioned by Singh et al. (2012). By finding the adequate dosage, at the second stage 20 additional bricks are made, to check whether it is possible to remove the cure in the manufacturing process.

Specimen dimensions

The dimensions proposed are considered in agreement with the result reported by Betancourt et al. (2015), who state that neither shape nor dimensions affect compression strenght in concrete with marble dust. Wood was used for the casts to make the bricks, which makes it easier to take apart and handle the cast.

Trial matrix

For the dosages proposed in this study, the cement percentages by Rangel y Nevarez (2004) were used as a baseline, as they considered 12% and 15% of cement. These percentages are used in order to have in the mixture a higher amount of marble dust and, consequently, to get the brick to contain more than 62% of marble dust. This, in spite of the studies by Santos et al. (2012), Bilgin et al. (2012) and Corinaldesi, Moriconi and Naik (2012), where they showed that if more than 10% of marble dust is substituted, it affects the cement compression strenght and flexion. Likewise, Singh, Srivastava and Bhunia (2017), and Singh, Choudhary, Srivastava, Singh and Bhunia et al. (2017) found that it is possible to substitute up to 15% of cement for marble dust without there being a diminishing in compression strenght.

In the 16 dosages, amounts of cement, lime and sand were modified but preserving the quality of the marble dust. First, amounts of cement were modified to use a lesser amount of this material. River sand was substituted for ground sand from lime stone since in the area where this study takes place river sand is scarce. Lime for masonry work was added in order to test local practices and the benefit or damage generated by this product when mixed with cement.

Tables 2 and 3 show dosages in the mixtures that had 12% and 15% of cement, respectively. For each dosage, 10 samples were used out of which three were tried at seven days; three others, at 14 days; and three additional ones at 28 days. And a piece was left as control. In all cases, the control piece was also tested as part of the specimens.

Lime percentages in the mixtures were estimated based on the amount of cement added. The values for the other materials were estimated based on the amount of marble dust in the mixture. This way, as shown in Tables 2 and 3, 160 pieces made for this study are included.

In the dosages for the research two cement percentages were studied (12% and 15%) in order to verify whether it is possible to decrease the amount of cement necessary so that the brick reaches the minimum compression strenght to be considered a structural brick. In general, what was sought with these dosages was to achieve the compressive strength of 6.9 MPa indicated by the NMX-C-404 (2012) standard for solid structural bricks with lengths < 300 mm.

Lot No.	Marble dust	Sand	Water	Cement	Lime
1	15 kg	20 % (river)	35 %	12,00 %	-
2		20 % (ground)		12,00 %	-
3		20 % (river)	20 %*	11,40 %	5 %
4		20 % (ground)		11,40 %	5 %
5		20 % (river)		10,80 %	10 %
6		20 % (ground)		10,80 %	10 %
7		20 % (river)		10,20 %	15 %
8		20 % (ground)		10,20 %	15 %

Table 2. Mixtures with 12% of cement

Source: The authors' (2018). CC BY-NC-SA

Lot No.	Marble dust	Sand	Water	Cement	Lime
9	15 kg	20 % (river)	20%	15,00 %	-
10		20 % (ground)		15,00 %	-
11		20 % (river)		14,24 %	5 %
12		20 % (ground)		14,24 %	5 %
13		20 % (river)		13,50 %	10 %
14		20 % (ground)		13,50 %	10 %
15		20 % (river)		12,74 %	15 %
16		20 % (ground)		12,74 %	15 %

Table 3. Mixtures with 15% of cement.

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To make these bricks a mixture was made using dry aggregates. Amounts are those shown in Tables 2 and 3; they were mixed and, finally, water was added to have a mixture with the adequate consistence to be put into the casts.

Filling up the casts with the mixture was carried out in two stages, whereby one coat of approximately half the height and four or five strokes were given around the cast; and in the second coat, the same was done, and they were levelled up without any compacting.

Results

Brick manufacturing

The marble powder that is extracted from the storage location has some residues, such as dirt or clots; the latter result from humidity brought about by air or rain. Because of this, it was necessary to pass the material through a No. 40 sieve (0,42 mm) and, this way, to separate the marble pieces from the clots and dirt. Pieces of marble and dirt must be taken away from the material, but the clots may be pounded to turn them into powder. Similar to marble dust, river sand can also be sieved using a No. 4 sieve (4,76 mm) to extract the stones or residues it may have.

Once the materials have the cleaning characteristics and required dimensions, marble dust, sand and cement are dry mixed to obtain a homogeneous mixture of aggregates. Once the materials are dry mixed, water is added. The first amount of water must be the one stated in each dosage, and then some more water is added according to the mix needs so it can be placed in the centering and solid pieces may be obtained. For the case study, the initial amount of water, established in the dosage of 20% or 35% was not sufficient, and 5% more water was added.

A release agent was applied to the formwork to prevent the bricks from sticking to the formwork when they were removed from the mold. In this case, the casts were covered with used car oil to facilitate the extraction of the pieces from the container. In this study, the said material was used since it was easy to get, it does not contaminate the environment, and it does not generate any secondary effect on the pieces such as, for example, that they are left with some inappropriate color or smell, or that they may lose their compression strenght.

From each mixture 10 specimens were obtained, identified by the series L1-M1 to L1-M10 (Lot 1, Sample 1 up to 10, etc.). These specimens were water saturated and cured for 7, 14 and 28 days before being tried for compression. Figure 1 shows the 10 specimens with their corresponding nomenclature.

At the first stage, the cure consisted of saturating the water in the bricks since it is the most common curing process. At the second stage, the aim is to eliminate the cure by the amount of water used, and to verify if this is feasible; in this process, 20 additional bricks are made with the dosage that provides a better behavior during compression, out of the 16 ones studied during the first stage. The 20 bricks will be divided into 2 groups; 10 bricks will be cured and the other 10 won't, in order to compare their compression capacity and to define whether it is convenient to omit curing the bricks.

Trial description

For the compression trial it is necessary to let the bricks dry fully since, if any moisture is left in, it will help the dust to comprise in the face of the load. This way bricks may not show any fault and higher results, though not trustworthy, would be obtained. Therefore, bricks were left outside to dry for 24 hours before the compression trial.

For the brick absorption test the procedure indicated by norm NMX-C-037-ONNCCE-2013 was used. So, 3 brick specimens for each dose were used, and they were soaked into water for 24 hours. The specimens' absorption capacity was calculated using equation 1. This parameter allowed to obtain the percentage of water absorbed by each brick.

$$H\% = \frac{ph - ps}{ps} \times 100 \qquad (1)$$

Where *H* is the humidity percentage absorbed by the piece, and *ph* and *ps* are the weight of the humid and dry pieces, 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 generate the possibility that these bricks would not be able to adhere to each other, thus causing them to fail to achieve adequate compressive strength. The adhesion tests between the bricks were done based on the guidelines of the NMX-C-082-ONNCCE-2013 standard. The samples used for the adhesion tests between bricks are the same ones that correspond to the three walls built to determine the compression strenght in the small walls.

The small walls were built with bricks not cured; for this, instructions from the Federal District Complementary Standards for Masonry (F. D. Official Gazette, 2004) were followed. The small walls are made of three bricks onto which a vertical load was placed to determine their compression strenght. The mortar used to bind the pieces was cured, and the necessary time was provided so that the mortar would reach the adequate compression strenght 8,5 MPa.

When building the small walls, the nozzle used was 6 mm, according to the recommendations made by Salais and Ponce (2015). The 1:4 proportion mortar-cement-sand used complies with the recommendation made by Arragaña et al. (2016), which states which is the proportion that reaches an 8,5 MPa compression strenght.

Trial Results

Figure 2 shows the variation of compression strenght of the bricks at 7, 14, and 28 days of age, of the 16 dosages. To determine resistance, a contact area was considered in the application of the 18.400 mm2 load. It can be observed in Figure 2 that compression strenght at 7 days is higher under dosage 7, which has river sand, 10,2% cement, and 15% lime. At 14 days, dosage 7 showed the highest resistance. Lastly, at 28 days, dosages 12 and 16 were the ones showing the highest compression strenght. The amount of cement for dosage 12 is 1,5% higher than the amount of cement for dosage 16.

The results of resistance to compression shown in Figure 2 allow to deduce that resistance increases rapidly between 0 and 7 days of age, reaching approximately 82% of maximum resistance, whereas between 7 and 14 days, the increase of compression strenght is small: it approximately rises to 15%; and with an age of between 14 and 28 days its increase is even lower, approximately 3%. The trial was conducted according to NMX-C-036-ONNCCE-2013.

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Figure 1. Specimen samples from Lot 1.
Source: The authors' (2018). CC BY-NC-SA

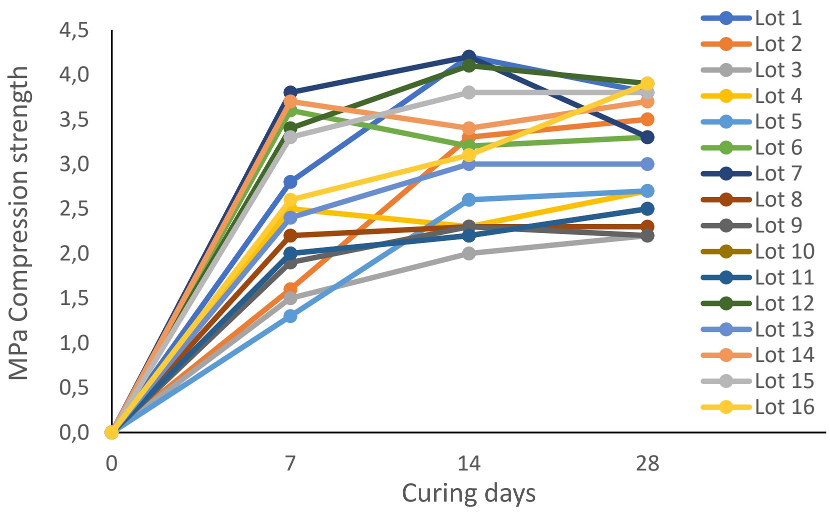

Figure 2. Variation of compression strenght for bricks and the days for their curing.
Source: The authors' (2018) CC BY-NC-SA

Variation in compression strenght between 14 and 28 days is 0,06 MPa; therefore, resistance at 14 days may be considered acceptable, omitting a 28-day trial. Kore and Vyas (2016) found that compression strenght at 28 days, of pieces containing marble mud, varied by 18% in relation to samples that do not have it. The said authors argued that the fact that there is marble dust does not significantly affect resistance increase at 28 days.

Table 4 shows the average results of the trial lots of the specimens for compression at 7, 14, and 28 days, as well as the standard deviation and the variation coefficient of the results. In the first column of the table the group of samples is shown, which, for this case, corresponds to the 16 dosages tried. The next three columns contain the information at 7 days of age of the samples with the average compression resistance, which corresponds to 2.53 MPa, as well as the standard deviation, with 0.79 MPa, and the coefficient of variation, with 31.3 %, respectively.

Table 4 shows that bricks have a low compressive strength, due to the amount of marble dust, because the more marble dust is added to a concrete mix, the more the compressive and flexural strength decreases, according to Santos et al. (2012), Bilgin et al. (2012) and Corinaldesi et al.

Absorption trials evidenced that the average value of water absorption is 21%, and that the variation coefficient is 7,7%. The said absorption value is higher than the 19% value limit as indicated by standard NMX-C-037-ONNCCE-2013.

This is due to the amount of marble dust in the bricks since Calcium Oxide (CaO) is quite reactive and, when in contact with water, it forms Calcium Hydroxide (CaO (OH)2), (Bilgin et al. 2012), which generates porosity in the bricks and, consequently, a higher absorption; therefore, bricks do not meet the limit absorption value, and moisture absorption in the bricks must be improved.

It is worthwhile to mention that the absorption found coincides with the results obtained by Bilgin et al. (2012), which show that when adding 70% marble dust to the cement to make bricks, between 30% and 40% absorption is obtained; therefore, it can be said that if marble dust is increased in a mixture, absorption is also increased.

Group	Day 7			Day 14			Day 28		
	MPa Average	σ	V.C. (%)	MPa Average	Σ	V.C. (%)	MPa Average	σ	V.C. (%)
1	2,53	0,79	31,3	3,01	0,74	24,80	3,07	0,62	20,5

Table 4. Compression strenght: average, standard deviation and V.C.
Source: the authors' (2018). CC BY-NC-SA

Figure 3 shows the compression trial of one of the walls. From the trials done on the walls it was found that the average value of compression strenght is 1,9 MPa, with a 15,3% variation coefficient. In the same figure it can be seen how the specimen keeps the bricks joined together by means of the mortar, which evidences their good adherence to work under compression. To make the walls, it was necessary to moisten the bricks; if they are not moistened, not enough adherence is obtained when they are joined by the mortar.

As of the results of the compression trials, in this study it is considered that performance of dosage 16 is the best, taking into account that the said dosage has the lowest amount of cement, and it has ground sand; in addition, it shows a growing behavior in the results of the compression trials. With dosage 16 twenty additional bricks were made, divided into two groups of 10 pieces each.

A set of 10 pieces was subjected to curing with the procedures recommended by standard NMX-C-148-ONNCCE2007. The second set of 10 pieces was not subjected to any type of cure. In this study, the trial is carried out of cured bricks and bricks not cured subjected to compression. The two new lots of 10 pieces were subjected to compression trials at 7 and 14 days, when it was considered that in the 16 dosages tried during the previous stage no meaningful increases were observed in compression strenght between the trials at 14 and 28 days of age.

Figure 3. Small brick walls.
Source: The authors' (2018)

Group	Day 7		Day 14	
	MPa Average	V. C. (%)	MPa Average	V. C. (%)
1	2,6	12	3,1	14
2	2,6	14	2,5	16

Table 5. Average value for compression strenght
Source: The authors' (2018)

Table 5 shows the average values of compression strenght of the cured bricks and those not cured. In this table, group 1 corresponds to the cured bricks; and group 2, to the ones not cured. In this table is also observed that at 14 days there is a 20% difference between the cured bricks and the ones not cured. The said difference indicates that it is not necessary to have a cure in order to obtain more compression strenght in the pieces since the 3,1 MPa resistance is adequate to work under compression in walls for low-height houses.

Discussion

Resistances under compression obtained with lower values than those required by the standard are due to the amount of marble dust in the piece, as mentioned by Singh et al. (2017) and Santos et al. (2012): when increasing the amount of marble dust, compression strenght diminishes; therefore, the values suggested by Singh et al. (2017) and Santos et al. (2012) to be substituted are 10% marble dust for cement so that compression strenght is not affected.

For this study, a 62% marble dust was used, at a higher percentage than the one recommended by Singh et al. (2017) and Santos et al. (2012), which affects compression strenght; therefore, in order to get the bricks to reach 6,9 MPa as recommended by the Mexican Norm (NMX-C-404ONNCCE-2012) for structural bricks, trials with dosages must be continued, or professional manufacturing techniques must be proposed to reach the said value.

Manufacturing bricks based on marble dust is possible, as mentioned by Betancourt et al. (2015) as well as by Rangel and Nevarez (2014); by not being subjected to a baking process, the environmental impact is reduced. Bilgin et al. (2012) mention that by adding marble dust to bricks contributes to lower costs since waste material is being used and, at the same time, support for ecology is provided. Gencel et al. (2012) conclude that the blocks manufactured by them with marble dust have better resistance to abrasive wear.

In this work, the adequate technique to manufacture bricks was defined. In addition, an ideal dosage was found so that they will reach the compression strenght for non-structural elements, according to the standard. The correct way was also found to mix the materials and, finally, a cast was made so that the pieces would have a correct appearance without their getting damaged. Based on this, it is possible to make masonry walls for low-height houses with non-structural elements.

Conclusions

The experimental results reported in this article show that it is feasible to make bricks based on marble dust to construct masonry walls for low-height houses, up to 3,5 m, in zones under low seismic threat.

In this work the dosage with the best performance under compression and adherence was established, as well as a more economic mixture, by substituting cement for commercial masonry lime.

The dosage that shows good results for the manufacture of these bricks is number 16, made of 12.74% cement and 15% lime. This way, marble dust is used in order to lower contamination produced by the accumulation of this type of dust in the open.

Regarding absorption, the result obtained is 21% which, at the same time, shows a 2% difference with the maximum 19% set by the norm. Brick absorption affects the moisture lost by the mortar when the pieces are joined. This effect is solved by applying an amount of water to the bricks before they are put together with the mortar.

Not moistening the bricks makes them take in all the mortar humidity, which makes it lose adherence by the loss of humidity. Moistening the bricks also helps to remove all the dust they may have

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and, if the said dust is removed, a better adherence is obtained. From the adherence obtained, it is concluded that it is enough between the pieces so that they can work under compression without having to add any modification to the brick or the mortar.

The cure may be omitted when manufacturing bricks, since the difference in resistances between the cured bricks and those not cured is 20%, and such an increase is not meaningful.

Vertical compression in walls show 1,9MPa results, which are considered acceptable to be used for house walls since this material is the more adequate than the one presently being used (urban wastes).

For the dosages tried, it was observed how the mixtures showing higher values for compression strenght are the ones that have ground lime sand instead of river sand. Another advantage of dosage 16, selected as the most adequate one, is that it obtains a compression strenght with less amount of cement, in comparison with what is contained in dosage 12.

The low values for compression strenght indicate that it is necessary to continue studying new dosages that permit to reach the 6,9MPa resistance stipulated by the Mexican norm (NMX-C-404ONNCCE-2012). To modify the dosages, chemical and physical studies of the materials must be done in order to set the adequate dosage of the aggregates to reach the compression strenght needed in structural bricks.

Once the correct dosage and the compression strenght of structural pieces are defined, trials must be effected to find the properties of the materials, such as stress, elasticity module, and the analysis of the life cycle.

Finally, in future studies the aim is to construct masonry walls in a 1:1 scale for a low-height house, and to validate the results obtained in this research work.

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