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SUSTAINABLE MORTAR BASED ON LIME (CAO), STONE POWDER AND HIGH-DENSITY POLYETHYLENE HDPE

SUSTAINABLE MORTAR BASED ON LIME CA (OH)2, STONE DUST AND HIGH DENSITY POLYETHYLENE HDPE

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Summary. - Mortars are mixtures for manufacturing blocks used in the construction industry are made with sand (non-renewable aggregate), which is the second most consumed raw material by man after water and cement, which has been proven to emit carbon dioxide (CO_2) when produced. Therefore, the objective of this research was to substitute in mortar mixtures CaO lime as a percentage of cement and waste stone powder (PP) together with high density polyethylene (HDPE) as a percentage of sand. control specimens were made in a 1:6 ratio as indicated in the builder's manual for blocks and three T treatments (lime, PP, HDPE) making 14 specimens for each mixture T1(2.5%, 2.5%, 2.5%), T2(5%, 2.5%, 5%) and T3(7.5%, 2.5%, 7.5%) respecting the NMX-C-111-ONNCCE-2017, NMX-C-159-ONNCCE-2016. Resistance at R (7, 14, 28) days was evaluated in triplicate completely at random with the NMX-C-083-ONNCCE-2020, NMX-C-109-ONNCCE-2013. Los response results were for R-Test (72.08, 73.64, 100.08) kg/cm^2, R-T1(39.98, 41.76, 56.02) kg/cm^2, R-T2(33.04, 34.77, 49.21) kg/cm^2, R-T3(22.05, 24.33, 33.41) kg/cm^2. None of the treatments complied with NMX-C-404-ONNCCE-2012 which requests 90 kg/cm^2 for structural blocks, it is concluded that T1 and T2 comply with NMX-C-441-ONNCCE-2013 which determines 35kg/cm^2 for non-structural blocks.

Key words: lime, dust, polyethylene, resistance, regulations.

Abstract . – Mortars are mixtures to make blocks used in the construction industry, they are made with sand (non-renewable aggregate) which is the second most consumed raw material by man after water and cement, which has been proven to emit carbon dioxide when produced (CO_2). Therefore, the objective of this research was to replace lime CaO in mortar mixtures in percentage in cement and waste stone powder (PP) together with high density polyethylene (HDPE) in percentage in sand . Control specimens were made in a 1:6 ratio as indicated in the builder's manual for blocks and three T treatments (Lime, PP, HDPE) making 14 specimens for each mix T1(2.5%, 2.5%, .5%), T2(5%, 2.5%, 5%) and T3(7.5%, 2.5%, 7.5%) respecting the NMX-C-111-ONNCCE-2017, NMX-C-159-ONNCCE-2016. The resistance at R (7, 14, 28) days with the NMX-C-083-ONNCCE-2020, NMX-C-ONNCCE-2020, NMX-C-ONNCCE-2016.
109-ONNCCE-2013 were evaluated in triplicate completely at random. The response results were for R-Witness (72.08, 73.64, 100.08) kg/cm^2, R-W1(39.98, 41.76, 56.02) kg/cm^2, R-W2(33.04, 34.77, 49.21) kg/cm^2, R-W3(22.05, 24.33, 33.41) kg/cm^2. None of the treatments complied with the NMX-C-404-ONNCCE-2012 that requests 90 kg/cm^2 for structural blocks, it is concluded that T1 and T2 comply with the NMX-C-441-ONNCCE- 2013 that determines 35 kg/cm^2 for non-structural blocks.

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INTRODUCTION

Cement is the key ingredient in mortars and concretes shaping much of the constructions around us, producing it leaves a huge carbon footprint and is the source of approximately 8% of the world's carbon dioxide (CO_2) , according to the British think tank Chatham House, in addition its high costs [1]. Other most commonly used building materials on our planet are sand and gravel reported the United Nations Environment Program [2], with sand (aggregate) being a crucial resource for the development of society and is the second most consumed raw material by man after water [3].

It is relevant to mention that lime CaO is a material used in the construction industry that is used in the preparation of mortars or masonry mixtures to join the materials with which walls, foundations and slabs are built, to mention a few, since its use is wide, It is stated that a mortar with lime allows the mixtures to retain moisture for a longer time (a property that the mixtures must have for proper curing), so adding it to the mixture will prevent possible cracks due to shrinkage, thus ensuring the quality of the mortars that include it in their mixtures [4].

Residual stone dust (PP) is generated from the crushing of rock from hills and is regularly deposited in the environment on soils, affecting vegetation, which decreases its capacity to absorb atmospheric carbon dioxide, water and solar energy, and these fine dusts also cause problems in the respiratory system, allergies or even death in humans. It has also been shown that materials such as high-density polyethylene (HDPE), used in packaging, when disposed of in the environment, cause problems for earthworms in the soil, reducing their life span and causing them to lose 3% of their body weight, with negative impacts on agriculture, which is vital food sovereignty [5]. It should be noted that the use of stone powder (PP), which has high density, combined with polyethylene (HDPE), which has low density, guarantees a balance in mortar mixtures, since PP provides resistance and HDPE provides low weight.

Therefore, researchers have set themselves the goal of searching for alternatives for new mortars that are environmentally friendly. In Ecuador, they evaluated adobe bricks containing cangahua, lime, clay and straw that presented mechanical characteristics in accordance with the standards. The best results in terms of resistance were obtained when using only cangahua, as well as when using clay in percentages of 10% and 20% in volume, and they affirm that they amply complied with Peruvian standard E.80 (10.2 kg/cm^2).

The impact of hydrated lime from artisanal and industrial sources when combined with cangahua decreased the compressive strength of mortars [6]. In Honduras they evaluated mixtures replacing lime with cement at 25%, 30%, 35%, 40%, 45%, all their experiments were evaluated with the ACI and ASTM standards, they manufactured blocks with these mixtures and the one that presented better resistance at 7 days within the proposed iterations was the one with 30% lime substitution with (59.76 kg/cm^2) and absorption of 0.0002 (kg/cm^3) [7]. In Spain they developed specimens with lime and ashes as binders and the highest values for mechanical strength was
28.04 kg/cm^2 after 28 days of curing. Another specimen tested with the same mixture was carbonated in an accelerated manner, achieving 34.36 kg/cm^2 at 14 days of curing. For the highest resistances with specimens based on lime and white cement and specimens with carbonated lime and white cement, they presented 134.71 kg/cm^2 and 234.84 kg/cm^2 respectively at 35 days of curing. He made other specimens to which he added superplasticizers combining lime, cement and ashes obtained 90.55 kg/cm^2, the same carbonated mixture reached 111.66 kg/cm^2 both at 21 days of curing [8].

However, no reports have been found where lime CaO has been evaluated together with stone powder (PP) and high density polyethylene (HDPE), so, the objective of this research was to elaborate mortar mixtures incorporating CaO lime as a percentage in cement and waste stone powder (PP) obtained from the crushing of hill stone in gravel banks in Tabasco and which is not used together with recycled high density polyethylene (HDPE) as a percentage in the limestone sand of the Samaria River where it is extracted by dredging, evaluating if they could comply with the Mexican standards of compressive strength for blocks.

DEVELOPMENT

Materials and methods

Procurement of raw materials

Raw materials: CaO lime was provided by the company Calidra located in its offices on the Villahermosa-Cárdenas highway in Tabasco, stone powder, commercial cement and sand provided by the company Grupo SUPERICO S.A. de C.V., and high density polyethylene (HDPE) acquired from the Tabasco company POLIPLAST, a plastic recycling company located on the Villahermosa-Cárdenas highway in Tabasco, purchased by Grupo SUPERICO S.A. de C.V.

Grain size analysis

Taking NMX-C-111-ONNCCE-2017 as a guide, a granulometric analysis was performed on the materials known as fine aggregates, which were sand, residual stone powder (PP) and high-density polyethylene (HDPE). The three materials were sieved and the particles used in the mixtures were those that passed the 50 mesh, with diameters less than 0.297 mm to ensure that the particles were heterogeneous [9].

Density of materials

The density of cement, lime CaO, sand, residual stone powder (PP) and high density polyethylene (HDPE) was determined at the Research Laboratory II of the Tecnológico Nacional de México / I.T. Villahermosa, as established by the Mexican standard NMX-C- 571-ONNCCE-2021 [10].

Design of experimental mixtures

Three treatments of the mixes were designed where lime CaO is substituted as a percentage in the cement and stone powder is substituted as a percentage in the sand together with HDPE with different percentages, here we took as a theoretical basis the Cemex Concrete Builder's Manual page 19, Table 43 mortar proportions, finding that for blocks the appropriate ratio is 1:6 (a 50 kg bag of cement and 6 cans of 19L). [11].

Table 1. Percentages used in the specimens Witness 1:6 ratio for blocks.

Treatment	*Material*	*Percentage*
Witness	Cement	20 %
	Sand	80%

Note: Prepared by authors

Table 1 shows the percentages of cement and sand used in the design of the control samples and Table 2 shows the percentages of materials used in the design of the samples of the three treatments.

Percentages used in the specimens of three 1:6 ratio treatments for blocks.

Treatment	*Material*	*Percentage*
Treatment 1	Cement	17.5 %
	Sand	75%
	Cal	2.5%
	HDPE (PERT)	2.5%
	Powdered stone (PP)	2.5 %
Treatment 2	Cement	15 %
	Sand	72.5%
	Cal	5%
	HDPE (PERT)	5%
	Powdered stone (PP)	2.5 %
Treatment 3	Cement	12.5 %
	Sand	70%
	Cal	7.5%
	HDPE (PERT)	7.5%
	Powdered stone (PP)	2.5 %

Note: Prepared by authors

Elaboration of experimental samples

Based on NMX-C-159-ONNCCE-2016 and ASTM C1437 standards, specimens of the control mixture were prepared in cylindrical molds of 5 cm in diameter and 10 cm in height each, placing in the tray the amount of sand and cement calculated for the volume of 14 cylinders of 0.2749 m^3, see (Figure 1) [12] [13].

Figure 1. Mixture preparation and experimental cylinders Note: Taken by authors.

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After 48 hours all samples are demolded and placed suitable containers with water to start the curing process (Figure 2).

Figure 2. Curing of specimens at 7, 14 and 28 days Note: Taken by authors.

The above procedure was repeated for the three treatments (T1, T2, T3) this time CaO lime was included as a percentage in the cement and stone dust together with HDPE in the sand.

Compression test

Based on the standards: NMX-C-083-ONNCCE-2002, NMX-C-109-ONNCCE-2013 control specimens and three treatments were subjected to compressive strength tests [14] [15].

When the specimens reached the test age, they were removed from the storage tanks, covered with a damp cloth until the time of testing to prevent moisture loss, and transferred to the laboratory where the compression tests were carried out the recommended time tolerances.

Tolerances were taken into account from the moment specimens were removed from the water (Figure 3).

Figure 3. Cylinders just removed from the storage tank to prevent moisture loss.
Note: Taken by authors

Pitching of specimens

To obtain reliable results in the tests, the faces of the specimens must have flat surfaces, for which pitching is required, prepared with pure cement or sulfur mortar at the bases of the cylindrical specimens to achieve parallelism between the faces for the compression test. The sulfur mortar is prepared with a proportion of 75% sulfur and 25% sand, see (Figure 4 and 5).

Figure 4. Metal base for specimen pitching
Note: Taken by authors

Figure 5. Specimens with 75% sulfur and 25% sand mortar pitch. Note: Taken by authors

Testing of core and experimental specimens

The compressive strength test is carried out at 7, 14 and 28 days, which is performed on 3 specimens taken completely at random based on NXM-C-061-ONNCE and NMX-C-083-ONNCCE- 2020 standards [16] [17].

The specimen is placed in the machine by carefully centering it with respect to the upper plate. The load is applied steadily until the specimen ruptures on the faces of the specimens that had contact with the vertical walls of the mold see (Figure 6).

Figure 6. Compressive strength test. Note: Taken by authors

The results are recorded in a logbook.

Experimental design

The experimental run used a completely randomized design in a 4x3 factorial arrangement, with three replicates for the control and three treatments. The factors were the types of treatment (T, T1, T2, T3) and the compression test times (7, 14, 28) days.

Statistical analysis

All the results obtained were evaluated in the statistical program Statgraphics centurion XVI.II®. The quantitative response variables, compressive strength of the control and the three treatments, were compared. To determine if there were significant statistical differences, a comparison of several samples was carried out, where the method used to discriminate between the means was Fisher's LSD minimum significant difference procedure with a $p<0.05$ and a 95% confidence level. The resistance of each specimen was evaluated based on the results of the differences between the control and each treatment using the average data of the results as established by the Mexican standards for structural block NMX-C-404- ONNCCE-2012 (90kg/cm^2) and NON structural block NMX- C-441-ONNCCE-2013(35kg/cm^2) [18] [19].

DISCUSSION AND ANALYSIS OF RESULTS

Densities of materials

Table 3 presents the calculated densities for the raw materials are for sand 1669.67 kg/m^3, cement 1407.33 kg/m^3, Dirty HDPE 536 kg/m^3, Clean HDPE 424 kg/m^3, Stone Powder (PP) 1788 kg/m^3 and Lime CaO 816 kg/m(3).

Table 3. *Calculated densities of raw materials*

Densities of materials ($^{kg/m3}$)					
Sand	1669.67	**HDPE Dirty**	536	**P. d. Piedra**	1788
Cement	1407.33	**HDPE Cleaned**	424	**Cal**	816

Note: Prepared by authors

Evaluation of the resistance of the control and the three treatments

The strength was calculated with a destructive test, a compressive strength test. It was observed that in the three treatments the resistance decreased with respect to the control (Figure 7).

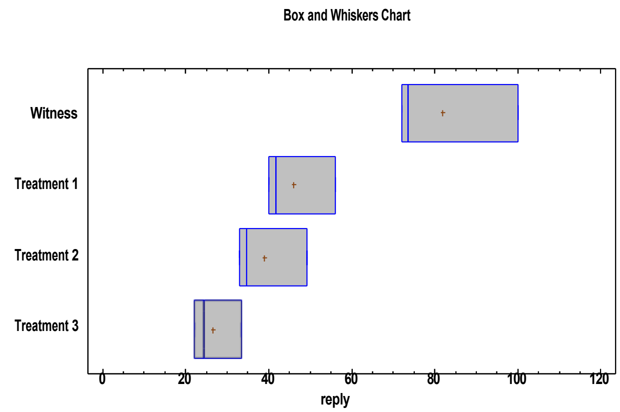


Figure 7. Compressive strength

Table 4 shows the results of the 3 treatments and the control of their resistances obtained in compression tests at ages 7, 14 and 28 days and subjected to a 28-day curing process.

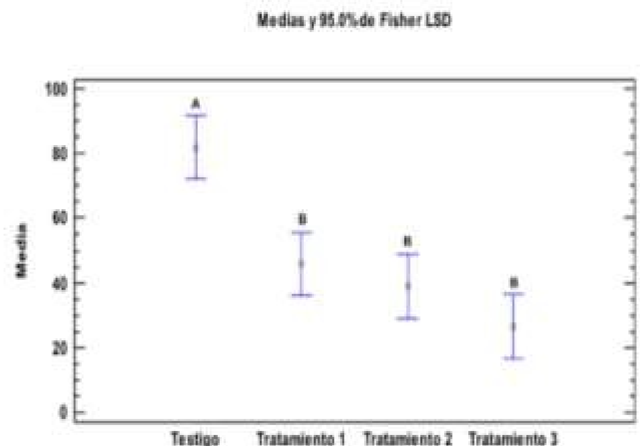
Table 4. Compressive strength data at 7, 14 and 28 days.

Treatment	*Days*	*Resistance* Cylinder 1	Cylinder 2	Cylinder 3	*Mexican Standards* STRUCTURAL NMX-C-404-ONNCCE-2012 90kg/cm²	NON-STRUCTURAL NMX-C-441-ONNCCE-2013 35kg/cm²
Witness	7	**72.08**	59.54	59.65	YES complies complies	YES
	14	**73.64**	72.08	73.01		
	28	97.28	100.01	**100.08**		
Treatment 1	7	**39.98**	42.27	41.25	NO complies	YES complies
	14	**41.76**	35.91	41.50		
	28	[illegible]02	[illegible]84	[illegible]		
Treatment 2	7	30.01	**33.04**	30.98	NO complies	YES complies
	14	**34.77**	34.75	33.66		
	28	47.54	**49.21**	47.64		
Treatment 3	7	**22.05**	23.00	22.97	NO complies	NOT compliant
	14	24.13	23.31	**24.33**		
	28	**33.41**	33.39	32.99		

Note: Prepared by authors

Resistance.

The analysis of comparison of several samples using the method employed to discriminate between the means was Fisher's LSD minimum significant difference procedure with a $p<0.05$ and with a 95% confidence level showed that there are significant differences between the control that reached a resistance at 28 days of 100.08 kg/cm² showing that the response variable resistance did have an impact on treatment 1, which reached 56.02 kg/cm², treatment 2 with 49.21 kg/cm² and finally treatment 3 with 33.41 kg/cm² See (Figure 8).



Note: Different letters show statistically significant differences (N=36).
Prepared by authors

Table 5 below shows the mean for each column of data. It also shows the standard error of each mean, which is a measure of your sampling variability. The standard error is the result of dividing the

standard deviation pooled among the number of observations at each level. The table also shows a

interval around each mean. The intervals currently shown are based on Fisher's Least Significant Difference (LSD) procedure. They are constructed in such a way that, if two means are

their intervals will overlap 95.0% of the time.
times.

Table 5. Table of means with confidence intervals of 95.0%.

	Cases	Mean	Error Est. (s grouped)	Lower Limit	Upper Limit
Witness	3	81.9333	6.05412	72.0615	91.8052
Treatment 1	3	45.92	6.05412	36.0482	55.7918
Treatment 2	3	39.0067	6.05412	29.1348	48.8785
Treatment 3	3	26.5967	6.05412	16.7248	36.4685
Total	12	48.3642			

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DISCUSSION

In Ecuador, they evaluated adobe bricks containing cangahua, lime, clay and straw that presented mechanical characteristics in accordance with the standards.
volume, they claim that they were fully compliant for the

Peruvian standard E.80 10.2 kg/cm^2). The impact of hydrated lime from artisanal and industrial sources when combined with cangahua decreased the compressive strength of the mortars (Viera et al., 2023). [6].

In contrast, the present investigation focused on the

design of experimental mortar mixes substituting lime CaO percentage in cement and waste stone powder (PP) together with high density polyethylene (HDPE) percentage in sand.

In Honduras they evaluated mixtures substituting lime for cement at 25%, 30%, 35%, 40%, 45%, all their experiments were evaluated with ACI and ASTM standards, they manufactured blocks with these mixtures and the one that presented the best resistance at 7 days within the proposed iterations was the 30% lime substitution with 850 [psi], which also presented an absorption of 10.93 [lb/ft^3] (Perdomo and García, 2022). [7]

In the present investigation, control specimens were produced in a 1:6 ratio as indicated in the builder's manual for blocks and three T treatments (Lime, PP, HDPE), producing 14 specimens for each mixture T1(2.5%, 2.5%, .5%), T2(5%, 2.5%, 5%) and T3(7.5%),
2.5%, 7.5%) respecting NMX-C-111-ONNCCE-2017,
NMX-C-159-ONNCCE-2016. Resistance at R (7, 14, 28) days was evaluated in triplicate completely at random with NMX-C-083-ONNCCE-2020, NMX-C-109- ONNCCE-2013.

The Escuela Politécnica Superior de Edificación de Barcelona, Spain, carried out an investigation where they elaborated specimens with lime and ashes as binders and the highest values for mechanical resistance were: specimen 1DH reached 2.75 N/mm^2 after 28 days of curing. The M3H2 with 3.37 N/mm^2, tested 14 days after curing, was accelerated carbonated, the "white" M3H2 with 12.94 N/mm^2, tested 14 days after curing, was accelerated carbonated in the same way. For the highest strengths with specimens based on lime and white cement, they found that the M4C3 reached 13.21 N/mm^2 35 days of curing, the "white" one presented 23.03 N/mm^2 at the same 35 days of curing. Within the results for samples to which superplasticizers were added, as well as the combination of lime and cement with ashes, achieved that M6HC5 obtained 8.88 N/mm^2 after 21 days of curing, the "white" reached 10.95 N/mm^2, after 21 days of curing (Lagares, 2018). [8]

Finally, in our research, the response results were for R-Witness (72.08, 73.64, 100.08).
kg/cm^2, R-T1(39.98, 41.76, 56.02) kg/cm^2, R-T2(33.04, 34.77, 49.21) kg/cm^2, R-T3(22.05, 24.33, 33.41) kg/cm^2.
None of the treatments complied with NMX-C-404-ONNCCE-2012, which requires 90 kg/cm^2 for structural blocks.
comply with NMX-C-441-ONNCCE-2013 that the for non-structural blocks.
determines 35kg/cm^2

CONCLUSIONS

Density

The results obtained showed that when lime was substituted as a percentage in the cement and HDPE together with PP in the sand, in ranges of 2.5% this change does decrease the weight of the specimens when compared to the weight of the control specimens, these results are attributed to the density of HDPE which was quite low with respect to the other raw materials used, these data coincide with that reported by Gómez *in* 2011, who substituted small amounts of HDPE in mortars (Gómez *et.al.*, 2011) [20].

Resistance

The compressive strength of the specimens of the three treatments where the percentage of lime in the cement and HDPE in the sand was varied and where the PP was kept constant, its substitution decreased with respect to the control specimens, coinciding with what was reported by Viera in 2023 and Perdomo et al. in 2022, who state that the use of lime in mortar mixtures decreases the strength. On the other hand, we can conclude that integrating PP in the mixtures allows the specimens to reach the strengths required by the Mexican standards, coinciding with the results of Lagares in 2018, who carbonated the mixtures to achieve this and only in this way was able to obtain higher strengths in his experimental specimens.

It is concluded that of the three treatments experimented in this research, treatments 1 and 2 achieved resistances that will allow their use in the manufacture of non-structural blocks, amply demonstrating that it is possible to safely reinsert waste that contaminate the environment in buildings without putting human beings at risk and offering an ecological and sustainable alternative.

As future lines of research, it is proposed to carry out new experiments by changing the percentage of lime, stone and HDPE in order to reduce costs and the carbon footprint of the cement, since although the compressive strength did not reach the structural level, there is enough margin to remain in the non-structural .

To scale up the results of this research for the manufacture of blocks and pavers for non-structural use in the construction industry.

Finally, the results obtained, in addition to with current regulations, ensure resistance, quality and safety, and also open the door to opportunities to improve the environment, reduce waste and promote recycling. The mixture developed is emerging as an ecological and efficient alternative that, after being endorsed by the Tecnológico Nacional de México campus Villahermosa and Grupo SUPERICO, will be implemented in the manufacture of ecological blocks.

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