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ENGLISH VERSION...

Masonry mortar design incorporating crushed recycled glass

Diseño de mortero para albañilería incorporando vidrio reciclado triturado

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Abstract

Mortar is considered one of the construction materials in great demand in the world, obtaining materials for its preparation require the exploitation of a large part of renewable and nonrenewable resources. In order to dissipate the consumption of natural aggregates, the reuse of different materials that are normally discarded has been studied; glass is an important option for the preparation of mortar. Therefore, the objective of the present investigation was to design a mortar for masonry incorporating crushed glass. The mixing design was made for dosages of 1: 3.5, 1: 4, 1: 5 and 1: 6 with substitution of 5%, 10%, 15%, 20%, 25% and 30% of fine aggregate by crushed glass; tested at the age of 7, 14, 21 and 28 days. The fluidity of the mortar in fresh state and the mechanical properties such as the resistance to compression and bending of the mortar, resistance to adhesion by bending in masonry piles, resistance to axial compression of piles and resistance to diagonal compression in walls were evaluated. of bricklayer. The highest resistance was obtained for the dosage of 1: 3.5 with 30% as the optimum percentage of substitution, reaching a higher resistance compared to the standard mortar; for the dosage of 1: 4 the optimum percentage was 25%; for 1: 5 it was determined with 20%; and finally, 10% was obtained as the best percentage for the 1: 6 dosages. From these values it was determined that, once the optimal percentages were reached, the strength of the mortar decreases as the substitution increases. The results obtained allowed to conclude that the crushed glass significantly influences the mortar properties.

Keywords: *Masonry; crushed glass; mortar fluidity; mechanical properties.*

Resumen

El mortero está considerado como uno de los materiales de construcción de gran demanda en el mundo, las obtenciones de materiales para su elaboración requieren de la explotación de gran parte de los recursos renovables y no renovables. A manera de disipar el consumo de agregados naturales se han estudiado la reutilización de diferentes materiales que normalmente son desechados, el vidrio se presenta como una opción importante para la elaboración del mortero. Por lo tanto, el objetivo de la presente investigación fue diseñar un mortero para albañilería incorporando vidrio triturado. El diseño de mezcla se realizó para dosificaciones de 1: 3.5, 1: 4, 1: 5 y 1: 6 con sustitución de 5%, 10%, 15%, 20%, 25% y 30% de agregado fino por vidrio triturado; ensayados a la edad de 7, 14, 21 y 28 días. Se evaluó la fluidez del mortero en estado fresco y las propiedades mecánicas como la resistencia a la compresión y flexión del mortero, resistencia a la adherencia por flexión en pilas de albañilería, resistencia a la compresión axial de pilas y resistencia a la compresión diagonal en muretes de albañilería. Se obtuvo la resistencia más alta para la dosificación de 1: 3.5 con el 30% como porcentaje óptimo de sustitución, alcanzando una resistencia superior en comparación con el mortero patrón; para la dosificación de 1: 4 el porcentaje óptimo fue de 25%; para 1: 5 se determinó con el 20%; y finalmente se obtuvo el 10% como mejor porcentaje para la dosificación de 1: 6. A partir de estos valores se determinó que, una vez alcanzado los porcentajes óptimos, la resistencia del mortero disminuye a medida que la sustitución aumenta. Los resultados obtenidos permitieron concluir que, el vidrio triturado influye significativamente en las propiedades mortero.

Palabras clave: Albañilería; vidrio triturado; fluidez del mortero; propiedades mecánicas.

1. Introduction

Over the years, concrete has undergone an important and rapid evolution, developing new technologies for concrete and mortars. For this, the appearance of additives and new resources that help to improve the properties required by the standards were important (García and Más, 2018). In the construction of buildings, these materials are vitally important elements worldwide, consuming approximately 20,000 million metric tons per year, which generated that between 1990 and 2005 the emission of carbon for the cement manufacturing process doubled (Muñoz et al., 2019). The CO_2 produced by cement elaborations are generated by fuel incineration and limestone incineration processes, this process generates approximately 33% of CO_2 emissions and limestone calcination about 66% (Torres et al., 2015).

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In concrete and mortar mixtures, cement is considered as one of the primary materials for its elaboration, working as a bonding agent between aggregates (Rahman and Uddin, 2018). The processing of this material emits 0.9 tons of CO_2 for the production of one ton of cement (Hasanbeigi et al., 2010). The proportion of energy use in terms of cement production related to fuel use and electricity use is relatively equivalent (Gursel and Ostertag, 2016). It is considered that in a range of 5 - 7% of the total CO_2 emissions correspond to the cement manufacturing process (Chen et al., 2010). Therefore, researchers dedicated to the industry propose as an alternative solution the recycling or reuse of waste as materials for the production of mortars and concretes, which can be used in different fields of construction according to the characteristics that the work requires (Cabrera et al., 2017). In Australia between 2014 and 2015, around 64 million tons of waste were produced, of which approximately 60% of waste was recycled, generating concern about the remaining waste that ends up in landfills or giving rise to environmental problems (Kazmi et al., 2020).

The use of wastes (fly ash, slag, glass dust, silica fume, etc.) as construction materials is intended to reduce the consumption of portland cement, which requires an energy-intensive process and generates the emission of greenhouse gases (Bazhumi et al., 2019). In addition, quality sands have been used in large quantities and their consumption is increasing; therefore, the use of recycled fine glass as a substitute for fine aggregate for the production of cementitious materials is proposed as an alternative solution (Hajimohammadi et al., 2018).

Glass is a versatile material used in products such as containers, building materials, laboratories, glass panels, etc. (Lye et al., 2017). The use of recycled glass have generated more attention in researches, where its use as a replacement of aggregate in concrete production is raised (Kamali and Ghahremaninezhad, 2016). In recent years, wastes such as recycled glass and fly ash have been the subject of study by many researchers, considering glass as a product composed of small particles, which could easily be replaced by sand or cement (Arulrajah et al., 2016). That is why the efforts to analyze the behavior of recycled glass as a total or fractional replacement of natural components in the production of concrete or mortars, saving more than one ton of virgin material for each ton of recycled glass (Rahman and Uddin, 2018).

The chemical composition of glass is fundamental to improve the alkali-silica reaction (Bignozzi et al., 2015). When recycled glass is used in mortars, it improves fresh properties and offers better resistance to sulfate attack and high temperaturas (Liu et al., 2019). Replacing natural aggregates with recycled glass generates improvements in workability; however, the higher the percentage of substitution the compressive strength is reduced (Lu and Poon, 2018). Glass powder in general manifests at 180 days mechanical properties up to 80% higher compared to the strength at 28 days (Corinaldesi et al., 2016).

The rate of reduction of compressive and flexural strength increases proportionally to the increase of glass in the mixture, the porosity in the mortar rises, the mixture in fresh state becomes more fluid resulting in flowability values higher than those established (110±5%); however, it is considered that crushed glass is favorable for making mortars with greater durability than conventional mortars (Choi et al., 2017). From the slump analysis performed on a mortar with recycled glass as a partial replacement of fine aggregate, it is evident that the flowability increases as more crushed glass is incorporated. The mix design indicates that the amount of water should be reduced to obtain good workability (Tuaum et al., 2018).

Mortars with crushed glass made with replacement percentages from 30% to its totality in a dosage of 1: 2 and tested at 28 days, show that replacement with percentages higher than 30% generate reductions in the axial compressive and flexural strength of the mortar as the amount increases, this due to the weak bond between the cement and the smooth glass aggregate (Gorospe et al., 2019). The higher the percentage of substitution the compressive and flexural strength decreases (Lu and Poon, 2018). From the comparison of the mortar with glass with a ratio of 1: 3 with 1: 5, it is determined that the compressive strength of the mortar grows by using a greater amount of cement and reducing the amount of fine aggregate, the results obtained in the analysis to cubic samples of mortar are directly related to the results of prisms and walls (Dehghan et al., 2018). It is not recommended to replace 100% of the fine aggregate, since it generates a considerable decrease in mechanical properties (Guo et al., 2018). By using replacement percentages of 5%, 10%, 15% and 20%, an increase proportional to the amount of glass used is obtained, the maximum compressive strength achieved compared to the base mortar was 29% higher, the flexural strength had an increase of 14%. The highest values were achieved with 20% replacement (Malek et al., 2020).

The analysis of prisms tested at 28 days, made with clay brick showed that, the ratio of 1: 3 and 1: 4 present joint failure between mortar and brick, in the ratio of 1:5 the failure is visualized in the joint (Nandurkar and Pande, 2018). The strength of prism is directly proportional to the strength of mortar and masonry unit (Thaickavil and Thomas, 2018). However, increased mortar strength does not always generate higher masonry strengths, due to factors such as variation in brick strength and low bonding capacity between masonry unit and mortar (Gumaste et al., 2007).

2. Materials and experimental procedure

2.1 Materials

All the materials used for this research will be selected according to their properties, considering the specifications required by the American Society of Testing Materials (ASTM).

The standard (ASTM C270-12, 2012), establishes the parameters of mortar to be used in masonry. It is considered as a mixture of materials (portland cement, hydrated lime, coarse sand and water) whose main purpose is to adhere masonry units, correct irregularities and cover joints to prevent air and water penetration. For the axial compression analysis of the mortars, the standard (ASTM C109-12, 2012), is considered, which proposes the elaboration of mortar cubes of 50 mm on each side. For this study, specimens were tested at 7, 14, 21 and 28 days.

The masonry units are analyzed in accordance with the standard (ASTM C134-95, 1995), Every unit or block manufactured must be evaluated and comply with the established measurements. In relation to the dimensions, there is a variety that depends on the work to be executed and the material used for its manufacture. Not all of them are intended to fulfill the same function, since they are used in the

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execution of different works. The masonry element used is considered a hollow unit, since it presents a percentage of void area of 49.82%, which is higher than 30%, being the maximum value of voids established by the RNE. (Norma E.070, 2006) for masonry of the RNE.

Natural coarse sand was used as fine aggregate, which should not contain organic matter and salts. When using granulometries different from those established in the standard (ASTM C136-06, 2006), it must be verified that the strengths of piles and walls comply with the specified values.

The fine aggregate for this research was obtained from the La Victoria quarry located in Pátapo, in the department of Lambayeque, Peru. A granulometric analysis was carried out on all the material passing through the No. 4 mesh, where the particle sizes were determined using different sieves with square openings, as specified in the (ASTM E11-09, 2009). as shown in (Table 1). The fine aggregate used in the mortar mix shall not exceed 1% by weight of brittle particles, and the fineness modulus shall not be less than 1.6 or greater than 2.5. See (Table 2).

Table 1. Sieves for particle size (analysis)

MESH ASTM	% PASSING
Nº 4 (4,75 mm)	100
Nº 8 (2,36 mm)	95 a 100
Nº 16 (1,18 mm)	70 a 100
Nº 30 (0,60 mm)	45 a 75
Nº 50 (0,30 mm)	10 a 35
Nº 100 (0,15 mm)	2 a 15
Nº200 (0,075 mm)	Less than 2

Source: Author

Table 2. Physical characteristics of fine aggregate

Test	Unit	Result
Modulus of fineness	Dimensionless	2,47
Bulk specific gravity	Gr/cm³	2,51
Absorption percentage	%	1,44
Wet loose unit weight	Kg/m³	1481
Dry loose unit weight	Kg/m³	1461
Wet compacted unit weight	Kg/m³	1716
Dry compacted unit weight	Kg/m³	1693
Moisture content	%	1,35

Source: Author

Type I portland cement is used for this research, with properties that comply with the parameters set forth in the standard (ASTM C150-07, 2007). This type of binder is considered for general use, as it is used in jobs that do not require special properties. Conceptualized as the most costly and stimulating material for concrete compared to other aggregates. The properties obtained by the mixture depend on the proportion and qualities of its components (Rivva, 2000).

The water used for the preparation of mortar mixtures was clean drinking water free of impurities, considering the definitions contemplated in (ASTM C1602-12, 2012). It is a fundamental component in the preparation of mortar or concrete mixtures. It is present in all phases of a building (cleaning of aggregates, curing and watering of concrete), so it must be free of any harmful substance (Arriola, 2009). One of the functions of water is to hydrate the cement and initiate a series of chemical reactions where cement-water combine to form a paste; this process is known as cement hydration and has the function of binding all the aggregates permanently once it has set and hardened.

The functions of water are to provide hydration of the cement and to provide workability to the mix. When it comes into contact with the cement, it generates a series of chemical reactions, the resulting combination gives rise to a paste that fulfills the function of binding the aggregates once it has set (Vargas, 2015).

The processing and exploitation of building materials are directly related to energy use; it is considered that, by making use of natural resources there is an energy consumption 20 times more than using recycled resources (Won et al., 2019). One way to mitigate the environmental impact is the substitution of natural materials with recycled waste (Salas et al., 2016). Products that present high silica capacity allow obtaining mortars with lower porosity, higher strength and more solid. Recycled glass is an important product in the composition of alkaline cements, as it provides improved mechanical strength in materials (Torres and Puertas, 2017). The chemical composition of glass, contemplated in the standard (ASTM C169-16, 2016); presents significant advantages compared to other materials, making glass a very changeable resource for construction, which offers its use in different fields of engineering. The glass used in this study, was obtained by recycling all types of bottles (variety of colors and shapes) that are normally part of household waste.

To be used as a component in the mortar mixture, it must go through a cleaning and grinding process for later analysis. See (Table 3).

Table 3. Physical characteristics of crushed glass

Test	Unit	Result
Modulus of fineness	Adimensional	2,57
Bulk specific gravity	Gr/cm^3	2,44
Absorption percentage	%	0,06
Wet loose unit weight	Kg/m^3	1484
Dry loose unit weight	Kg/m^3	1480
Wet compacted unit weight	Kg/m^3	1739
Dry compacted unit weight	Kg/m^3	1734
Moisture content	%	0,31

Source: Author

2.2 Mix design

In the procedure carried out at this point, the proportions of materials required for each proposed design were determined. With the data obtained from the flow test, the corresponding water-cement ratio was calculated for each dosage.

We worked with percentages of 0% (control sample), 5%, 10%, 15%, 20%, 25% and 30% (experimental samples); substituted according to the volume of fine aggregate by crushed glass. (Table 4), (Table 5), (Table 6) and (Table 7) show the water-cement ratio corresponding to each mortar dosage.

Table 4. Mortar mix design for a dosage of 1 : 3.5.

Porcentage	Dosage of 1 : 3,5					A/C Ratio
	Cement	:	Sand	:	Crushed glass	
0 %	1	:	3,5	:	0	0,826
5%	1	:	3,325	:	0,175	0,817
10%	1	:	3,150	:	0,350	0,775
15%	1	:	2,975	:	0,525	0,749
20%	1	:	2,800	:	0,700	0,725
25%	1	:	2,625	:	0,875	0,716
30%	1	:	2,450	:	1,050	0,704

Source: Author

Table 5. Mortar mix design for a dosage of 1 : 4.

Porcentage	Dosage of 1 : 4					A/C Ratio
	Cement	:	Sand	:	Crushed glass	
0 %	1	:	4	:	0	0,890
5%	1	:	3,80	:	0,20	0,853
10%	1	:	3,60	:	0,40	0,834
15%	1	:	3,40	:	0,60	0,805
20%	1	:	3,20	:	0,80	0,766
25%	1	:	3,00	:	1,00	0,746
30%	1	:	2,80	:	1,20	0,733

Source: Author

Table 6. Mortar mix design for a dosage of 1 : 5.

Porcentage	Dosage of 1 : 5					A/C Ratio
	Cement	:	Sand	:	Crushed glass	
0 %	1	:	5	:	0	1,080
5%	1	:	4,75	:	0.25	1,049
10%	1	:	4,50	:	0.50	1,006
15%	1	:	4,25	:	0.75	0,984
20%	1	:	4,00	:	1.00	0,965
25%	1	:	3,75	:	1.25	0,957
30%	1	:	3,50	:	1.50	0,941

Source: Author

Table 7. Mortar mix design for a dosage of 1 : 6.

Porcentage	Dosage of 1 : 6					A/C Ratio
	Cement	:	Sand	:	Crushed glass	
0 %	1	:	6	:	0	1,190
5%	1	:	5,70	:	0,30	1,173
10%	1	:	5,40	:	0,60	1,159
15%	1	:	5,10	:	0,90	1,141
20%	1	:	4,80	:	1,20	1,132
25%	1	:	4,50	:	1,50	1,113
30%	1	:	4,20	:	1,80	1,108

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Source: Author

The quantities of water used were determined for each percentage, in order to achieve good workability and a fluid mix.

2.3 Flowability of the mortar

The standard specifications for mortars established in (ASTM C1437-07, 2007), stipulates that the flowability should have a value of 110 ± 5%. Following this parameter, the test was carried out until values within the specified range were obtained in all the mixtures.

The workability of the mortar depends greatly on the percentage of fluidity that is reached; when the mixtures are outside the established limits, then the masses will be poorly workable, affecting the compressive strength and the mortar-brick adhesion. See (Figure 1).

Figure 1. Mortar flow test. (Source: Author).

2.4 Compressive strength of mortar

The criteria considered for this test are described in the Standard (ASTM C109-12, 2012), which is carried out by analyzing cubic mortar specimens with a side of 50 mm as shown in (Figure 2). Mortar strength is considered as the capacity of a specimen to resist compressive loads exerted axially on it, considering that poor strengths are obtained with a higher amount of cement and optimal percentages of glass.

Figure 2. Compressive strength of cubic specimens of 50 mm side. (Source: Author).

2.5 Flexural strength of mortar

The standard (ASTM C348-14, 2014), the specifications for the development of the flexural analysis of the mortar are described. Specimens 40mm wide, 40mm high and 160mm long were made, as shown in (Figure 3), as well as cubic specimens were made with a mortar of 110±5% of fluidity and tested at the age of 7, 14, 21 and 28 days.

Figure 3. 40mm x 40mm x 160 mm specimens tested in flexure. (Source: Author).

2.6 Compressive strength in prisms (f'm)

The analysis of compressive strength in masonry prisms is carried out according to the standard(ASTM C1314-12, 2012).

For the determination of the resistance, the prisms must be elaborated with dimensions that are easy to be stockpiled, transported and assembled in the test equipment, it will present a slenderness (height/thickness) of 2 to 5 (San Bartolomé et al., 2018). For the development of this study, the prisms were elaborated with masonry units, stacked and units with mortar. The failure of the specimen occurs when vertical cracking occurs and the detachment of the material begins. See (Figure 4).

Figure 4. Compressive strength in masonry prisms (f'm). (Source: Author).

2.7 Flexural bond strength in prisms

The test to measure the bond strength of the masonry units to the mortar was developed as described in the standard (ASTM C1072-13, 2013).

The specimens prepared present the same characteristics as those used in the axial compression analysis, tested at the age of 28 days. To apply the load, the prism is mounted on the testing equipment, placed on supports at each end of the lateral face as shown in (Figure 5).

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Figure 5. Flexural bond strength of prisms. (Source: Author).

2.8 Diagonal compressive strength of walls (V'm).

The Peruvian standard (NTP 339.621, 2004) which cites (ASTM E519-00, 2000) as its antecedent, defines this test as a method that allows determining the shear strength (V'm) by applying a diagonal load to the wall at a speed that allows reaching the maximum load in a range between 1 - 2 minutes, thus causing a diagonal tensile failure in the direction of the applied load. See (Figure 7). The elaborated specimens have a square shape with minimum dimensions of 600 mm x 600 mm, tested at the age of 28 days and counted from their elaboration as shown in (Figure 6). The equipment used must have sufficient compressive load capacity and meet the characteristics recorded in the (ASTM E4-03, 2003).

Figure 6. Elaboration of walls for diagonal compression test. (Source: Author).

Figure 6. Elaboration of walls for diagonal compression test. (Source: Author).

3. Results and discussion

3.1 Mix design

The proportions of 1: 3.5; 1: 4; 1: 5 and 1: 6 were worked with a water-cement ratio of 0.826; 0.890; 1.080 and 1;190 respectively for the standard mortar. The mortars elaborated with partial substitution (5%, 10%, 15%, 15%, 20%, 25% and 30%) of fine aggregate by crushed glass presented unfavorable workability as the amount of glass increases, results similar to those obtained by (Choi et al., 2017), which concludes that the mixture becomes more fluid with greater amount of glass; as described in (Figure 8). Resulting in flowability values higher than those established. Therefore, it was worked with a lower proportion of water compared to the standard mortar, a process carried out in all proportions with the aim of achieving the fluidity of 110±5%; likewise (Tuaum et al., 2018) determined with the mix design that the amount of water should be reduced to obtain a good workability. See (Table 4), (Table 5), (Table 6) and (Table 7).

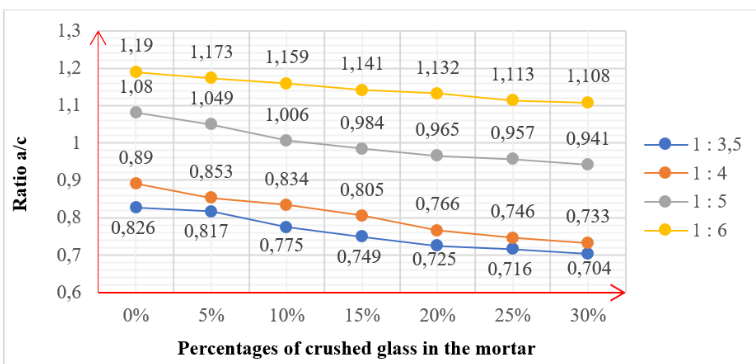

Figure 8. Water/cement ratio of the dosages used. (Source: Author).

3.2 Mechanical properties of the mortar

In the compressive strength analysis, the values obtained were favorable in all proportions, the specimens with glass exceeded the compressive and flexural strength of the standard mortar; these results are related to the research of (Malek et al., 2020) where a linear increase of the compressive strength analyzed up to 20% is evidenced. In the present study, optimal results were obtained with 30% and 25% for the dosages of 1:3.5 and 1: 4 (see (Figure 9)) confirming the results obtained by (Gorospe et al., 2019) where it shows that mortars made with percentages of crushed glass higher than 30% generate reductions in the axial compressive and flexural strength of the mortar.

For the dosage of 1: 5, the optimum compressive and flexural strength was achieved with 20% crushed glass. In the case of the dosage of 1: 6, optimum compressive strength was obtained with 15% and flexural strength with 10%, thus considering the value obtained in flexure as the optimum percentage for this dosage. The values determined in these proportions are supported by (Guo et al., 2018), recommends not replacing the fine aggregate in its entirety, since it generates a considerable decrease in compressive strength. See (Figure 9), (Figure 10), (Figure 11) and (Figure 12).

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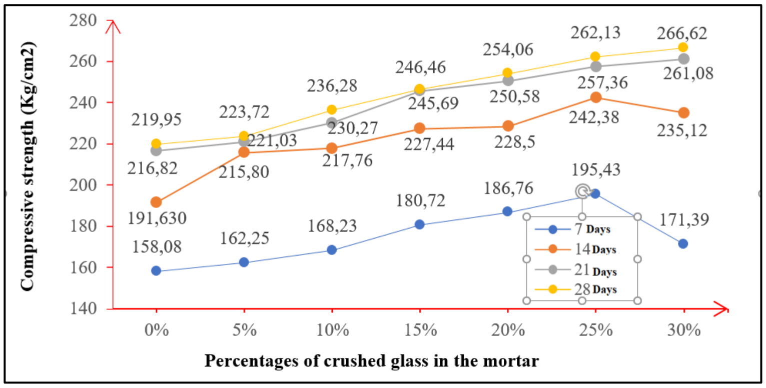

Figure 9. Res Compressive strength, analyzed at 7, 14, 21 and 28 days - Dosage of 1: 3.5.(Source: Author).

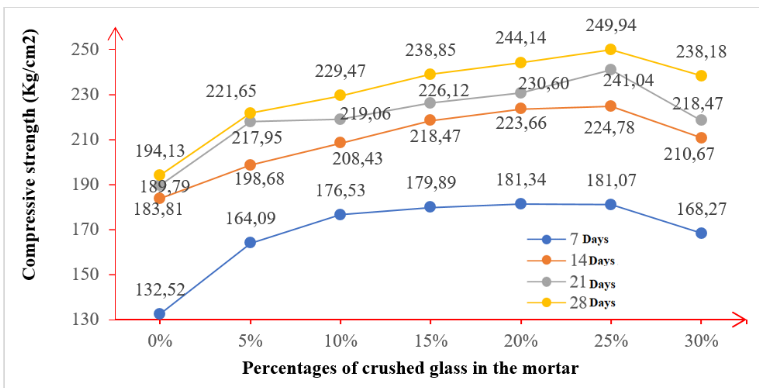

Figure 10. Compressive strength, analyzed at 7, 14, 21 and 28 days - Dosage of 1: 4. (Source: Author). (Source: Author).

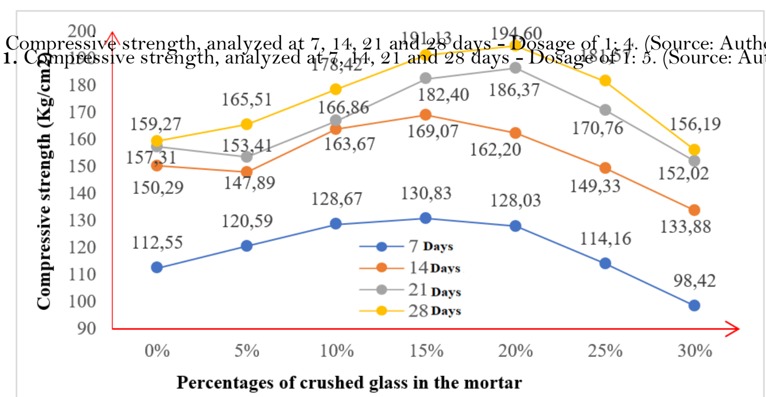

Figure 11. Compressive strength, analyzed at 7, 14, 21 and 28 days - Dosage of 1: 5. (Source: Author).Author). (Source: Author).

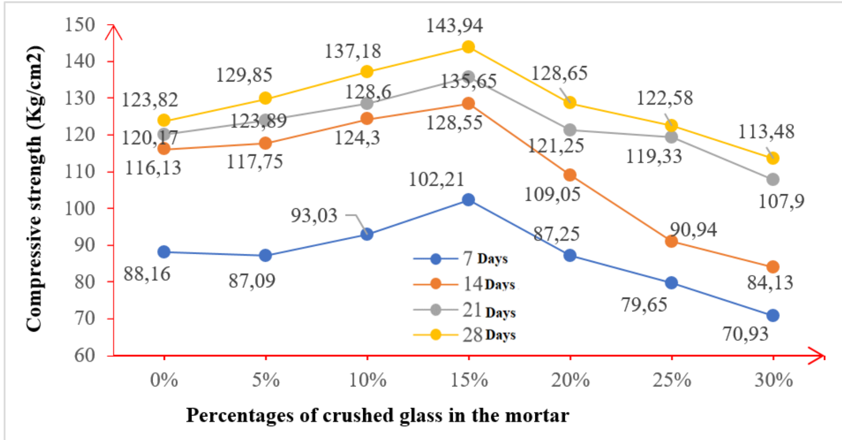

Figure 12. Compressive strength, analyzed at 7, 14, 21 and 28 days - Dosage of 1: 6. (Source: Author).

Considering the specifications of the standard (NTP 399.610, 2013) which cites (ASTM C270-12, 2012), The mortar elaborated with dosage 1:3.5 and 1:4 was classified as type M, due to the strengths reached in the standard model and with glass substitution that exceed the established value (175.39 kg/cm²). The mortar with dosage 1: 5; elaborated with percentages of 10%, 15%, 20% and 25% belongs to type M, for the case of 0% (standard), 5% and 30% it was classified as type S (126.44 kg/cm² ≤ S < 175.44 kg/cm²). For the 1:6 dosage, the strengths achieved with 5%, 10%, 15% and 20% glass belong to a type S mortar, while the specimens with 0% (standard), 25% and 30% glass correspond to a type N mortar (53.05 kg/cm² ≤ N < 126.44 kg/cm²).

4.2 Probability Distribution Characteristic of the Compressive Strength

The histogram for the distribution of the compressive strength datasets for the mixes has been shown in (Figure 2(A-E)). Histograms suggests that the distribution of the compressive strength data assumes a normal distribution and log-normal distribution. And a model curve can be fitted to the distribution reasonably. The normal and log-normal distribution curve has been overlapped over the histograms. The details of the proposed normal and log-normal distribution fit for the mixes has been presented in the subsequent sections.

3.3 Compressive strength in prisms (f'm)

(Dehghan et al., 2018), in their research states that the results obtained from the analysis of cubic mortar samples are directly related to the results of prisms and masonry walls, the present study confirms the above by obtaining similar results, in the test of axial compressive strength in prisms, made with conventional mortar and mortar with glass, it was determined that for a ratio of 1: 3.5 and with an optimal percentage of 30% glass, an increase in strength of 4.19% (134.19 kg/cm²) is achieved. For 1: 4 and 25% glass, the strength increased by 14.63% (129.25 kg/cm²). For 1: 5 and 20% glass, there was an increase of 4.64% (110.26 kg/cm²). With the dosage of 1:6, an increase in compressive strength of 8.24% was achieved. The data obtained agree with the study of (Thaickavil and Thomas, 2018), demonstrating that the prism strength is directly proportional to the compressive strength of the mortar and masonry unit. See (Figure 13).

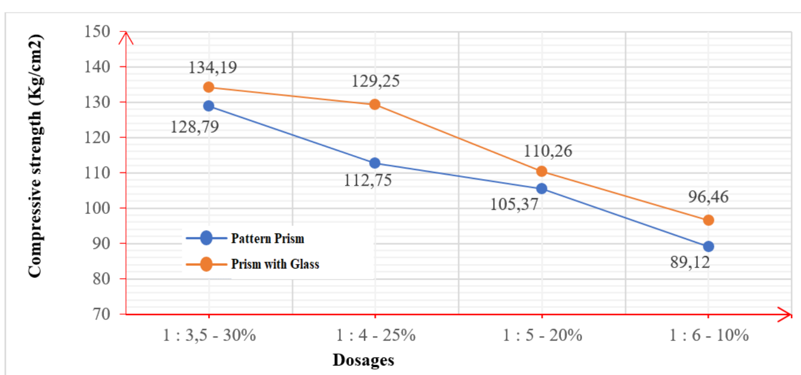

Figure 13. Compressive strength in prisms, analyzed at 28 days. (Source: Author).

According to the masonry unit used for this research (King Kong), the RNE E.070 - Masonry specifies that the resistance in masonry prisms must have a value greater than or equal to 65 kg/cm², a parameter that is met by obtaining superior results both in prisms made with standard mortar and with crushed glass. The resistance increase values achieved were obtained with the optimum percentages of each dosage.

3.4 Flexural bond strength in prisms

According to the analysis of adhesion between mortar and masonry element, it was determined that these results are related to the results obtained in compression. The prisms elaborated with mortar and glass surpass the resistances of the standard prisms in all the dosages. Referring to the amounts of substitution in the preparation of mortar, the optimum percentages determined were worked with, obtaining for the dosage of 1: 3.5 a value of 11.30 kg/cm², with an increase of 57% in adhesion resistance with respect to the standard resistance; for 1: 4, 10.24 kg/cm² was obtained, equivalent to a 58% increase in strength; for 1: 5, 7.07 kg/cm² was achieved, with a 47% increase; for 1: 6, a 51% increase in strength was achieved, with a value of 7.07 kg/cm². See (Figure 14).

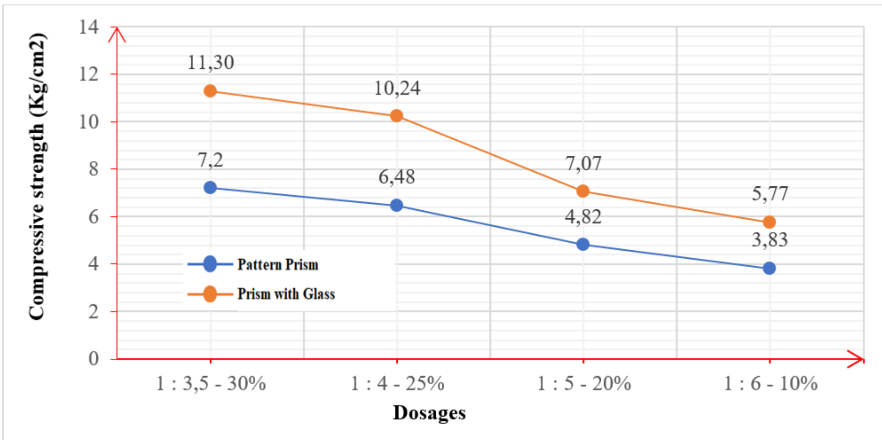

Figure 14. Compressive strength in prisms, analyzed at 28 days. (Source: Author).

3.5 Diagonal compressive strength of walls (V'm)

Analyzing the standard walls, it was determined that the highest value is 24.22 kg/cm² and corresponds to the walls made with a dosage of 1:3.5. In the case of the 1:4, 1:5 and 1:6 dosages, the results decrease as the amount of fine aggregate in the mix increases, thus obtaining values of 22.32 kg/cm², 21.34 kg/cm² and 18.91 kg/cm² respectively. See figure 15. Similar to (Nandurkar and Pande, 2018), failures are presented in the masonry unit, joint or mixed; action that depends on the proportion, compressive strength of the mortar and masonry unit used.

For the walls made with crushed glass, values of 30.63 kg/cm² were obtained for the dosage 1:3.5, 29.84 kg/cm² for 1:4, 28.68 kg/cm² for 1:5 and 27.35 kg/cm² for the dosage 1:6, resulting higher than the resistances of standard walls. See (Figure 15). These results respond to the values obtained in the analysis of mortar cubes; however, (Gumaste et al., 2007) concludes in their study that the increase in mortar resistance does not always generate greater resistance in masonry, due to the variation in the resistance of the masonry unit and the low bonding capacity with the mortar.

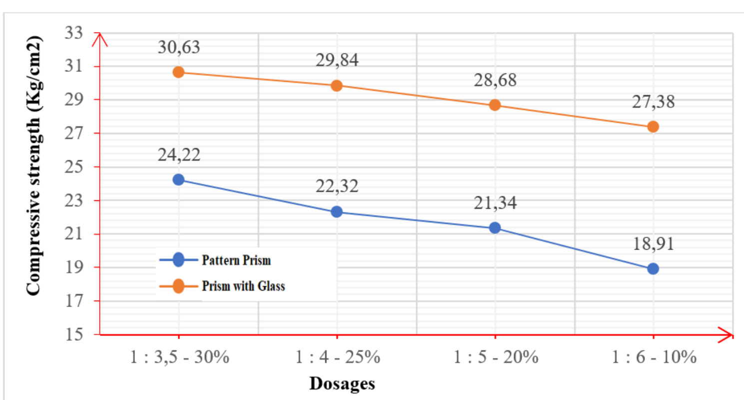

Figure 15. Diagonal compressive strength of walls, analyzed at 28 days. (Source: Author).

4. Conclusions

Percentages of 0%, 5%, 10%, 15%, 15%, 20%, 25% and 30% were used to replace the fine aggregate with recycled crushed glass in dosages of 1:3.5, 1:4, 1:5 and 1:6, with water/cement ratios of 0.826, 0.890, 1080 and 1.190 respectively for the standard mortar; for the mixtures with glass inclusion, proportions with lower amounts of water were determined, resulting in better workability.

From the analysis of compressive and flexural strength analyzed at 28 days, it is concluded that the mortars made with crushed glass present higher strengths compared to the standard mortars as the replacement percentage increases, as long as the optimum percentages are not exceeded; the dosage of 1: 3.5 reaches the highest values, with a compressive strength of 266.62 kg/cm² and flexural strength of 41. 17 kg/cm² with an optimum replacement percentage of 30%; the dosage of 1: 4 obtains a compressive strength of 249.94 kg/cm² and flexural strength of 39.14 kg/cm² with an optimum percentage of 25%; for the dosage of 1:5 it was 194. 60 kg/cm² in compression and 35.46 kg/cm² with a percentage of 20% and finally for the 1:6 dosage, a compressive strength of 143.94 kg/cm² and flexural strength of 27.31 kg/cm² were obtained with optimum percentages of 15% and 10%, respectively.

From the adhesion test between mortar and masonry element, it was concluded that the resistance of the mortar elaborated with glass and masonry unit in saturated conditions generated better mortar-brick joints. The prisms elaborated with mortar and glass generated for the dosage of 1: 3.5 a bond strength of 11.30 kg/cm², with an increase of 57% of bond strength with respect to the standard prisms; for 1: 4, 10. 24 kg/cm², equivalent to an increase of 58%; for 1: 5, 7.07 kg/cm² was obtained, with an increase of 47%; and for 1: 6, an increase of 51% was obtained, with a value of 7.07 kg/cm² of flexural bond strength.

Regarding the compressive strength, the prisms made with mortar and glass generated for the dosage of 1: 3.5 a compressive strength of 134.19 kg/cm², with an increase of 4.19% with respect to the standard prisms; for 1: 4, 129. 25 kg/cm², equivalent to an increase of 14.63%; for 1: 5, 110.26 kg/cm² was obtained, with an increase of 4.64%; and for 1: 6, an increase of 8.24% was obtained, with a value of 96.46 kg/cm² of axial compressive strength.

According to the results of the diagonal compression analysis, values above those obtained in the standard walls were achieved. The specimens were tested at 28 days, showed staggered and diagonal cracks in the standard walls; in the case of the samples with glass, diagonal cracks were visualized that went through mortar and brick. According to this evidence, it is concluded that there is a better adhesion of mortar and masonry element when crushed glass is used in the mixture.

Based on the results obtained from the different tests carried out at each stage of the mortar, it is generally concluded that recycled crushed glass significantly influences the properties of the mortar, taking into account not to exceed the optimum percentages for each dosage, and the strengths to be achieved.

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