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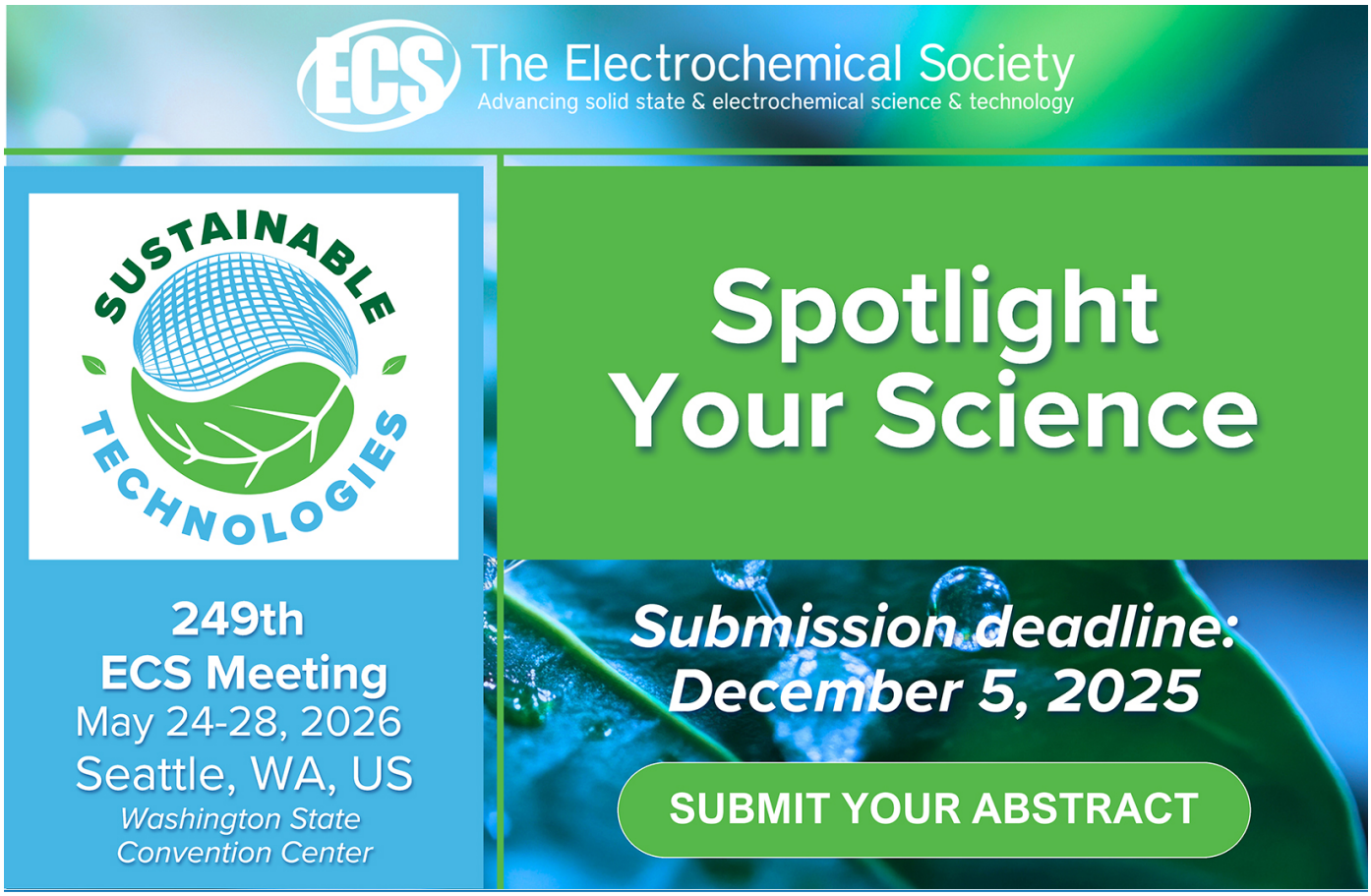
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Analysis of the variation of the physical properties of a mortar with replacement of cement by recycled glass

R J Gallardo Amaya[1], **C A Martínez Ovallos**[1], **and J Coronel Rojas**[1]
[1] Grupo de Investigación en Construcción, Geotecnia y Medio Ambiente, Universidad Francisco de Paula Santander, Seccional Ocaña, Colombia

E-mail: rjgallardoa@ufpso.edu.co

Abstract. Recycled glass, due to its high content of silica, can show some pozzolanic activity when it has a small enough particle size, this represents an alternative for the manufacture of mortars, as a partial substitute for portland cement, with which it is possible to reduce the waste of this material that can take up to 4000 years to degrade. This work studies the behavior of mortar mixtures with the addition of silica from recycled glass, and its impact on the values of fluidity, fineness, and density. The methodology was managed according to the factor analysis for the experimental design, finding two factors such as the curing time of the samples and the percentage of replacement of cement by the recycled glass, establishing percentages of 5%, 10%, 15%, 20%, 25% and 30%. The results obtained indicate a decrease in density up to 5.34%, additionally, the melt index was reduced to 13.65%, and the specific surface of the processed waste reached a value of 41.43% lower than the of cement. These results indicate that the project represents a viable alternative for the reincorporation of recycled materials to the production cycle, also contributing to the reduction of the impact generated by the construction industry, seeking new alternatives in the use of alternative materials.

1. Introduction

Mortar is considered one of the most important construction materials in this industry since it can have an important function in the elaboration of structural elements, in masonry as glue or filler material in the cells of the walls, as well as a non-structural function, allocating it to coatings in the case of plasters or paints [1]. For the mortar making, cement is the main ingredient, however, the production of one ton of portland cement releases approximately one ton of carbon dioxide (CO_2) to the atmosphere [2], additionally, it is known that 4 billion tons of cement are produced annually, contributing to the environmental problem with 8% of global emissions [3]. This situation constitutes a major environmental concern due to the high energy consumption and the growing demand for resources, being necessary for the implementation of strategies that considerably reduces the generation of waste and the optimization of resources.

Glass is another of the materials that due to its nature is imperishable and, therefore, harmful to the environment, according to United Nations data, the volume of solid waste produced annually worldwide is 200 million tons, of which 7% corresponds to the glass [4] and a considerable percentage of this ends up in landfills where it would take about four thousand years to degrade [5]. At the national level, according to data indicated in [6], 30% of the waste generated in Colombia is made up of materials that can be used as paper, metal, glass, textiles or plastic, but only 17% of these are recycled and the rest goes to sanitary landfills which, by 2030, will be reaching their maximum capacity in various cities of the country. As part of the strategies for the reuse of glass, its use in mortar mixes is proposed, since as

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mentioned in [7], glass reacts with cement and improves properties such as strength and durability, also, in [8] it was identified that the main advantage of the use of glass consists in the reduction of the density that translates into a lower weight of the structure.

In this sense, the partial replacement of cement with recycled materials such as pulverized glass would lead to a reduction in the use of cement and the consequent reduction in the environmental impact generated by its manufacture [9]. In [10] they propose that glass could behave as a pozzolanic material when the particle size is as fine as cement, due to its high content of silica in the amorphous state since pozzolans are defined as natural or artificial products, siliceous that in their natural state they lack binding properties, but finely ground and in the presence of water they have a chemical reaction with calcium hydroxide resulting in compounds with hydraulic and binding properties [11]. At the international level, various studies have been carried out concerning the residue of ground glass such as pozzolan, as carried out in [12], where the compressive strength of different mortar mixtures with substitution of ground glass by cement at different sizes was measured particle size, resulting in particles with diameters less than 38 μm having the best pozzolanic activity. Likewise, in [13] it was found that the resistance of the cement mixture at 90 days of curing increased with the glass content up to a 25%.

This work aims to analyze the behavior of mortar mixtures with the substitution of portland cement for finely ground flat glass residue, to determine the variation in the physical properties of the mortar, to identify, at a later stage of the investigation, the pozzolanic activity that has the substitution of this residue based on the Colombian Technical Standards and the standards of the American Society for Testing and Materials.

2. Materials and methods

The focus of the present study corresponds to a quantitative investigation of an experimental type, the variable of the dosage of the percentage of partial substitution, in a mortar, of portland cement for pulverized glass was used, and the influence that said substitution has on the properties was analyzed of the mortar. The pulverized glass residue is obtained from crushing the flat glass by means of the wear machine in two sessions of 500 turns with 24 spheres, and a subsequent screening in the 0.425 mm, 0.075mm and 0.038 mm meshes; obtaining a glass residue with a particle size of less than 38 μm; the cement used is general-purpose gray portland cement and the sand used for the mixture is standard graded sand, according to the provisions [14,15].

The glass residue is found as a partial substitute for cement in mortar mixes, establishing dosages of 0%, 5%, 10%, 15%, 20%, 25% and 30%, from which fluidity tests are obtained and Density measurement using 5 cm side mortar cubes. The experimental design by factor analysis showed the realization of 3 mortar cubes for each dosage randomly, according to [16]; in the case of fluidity, the water-cement ratio was set at 0.8, since the standard sample yielded a fluidity of 110 +/- 5, as established by [17]. The curing of the mortar specimens was carried out according to the provisions of [18].

3. Results

Raw material characterization tests were carried out for the mortar mixes, as well as tests to determine some physical properties of said mixes by varying the percentage of substitution, the results are shown below.

3.1. Raw materials

The cement used for mortar mixes is general use gray portland cement, the ground glass residue comes from flat glass obtained from different stained-glass windows in Ocaña, Colombia, and the fine aggregate for the mixture corresponds to graded normalized sand obtained from the quarry of the Rio Algodonal, Colombia. The density and specific surface area of Blaine were measured for both Portland cement and glass residue with a particle size of less than 38 μm, the density was made according to [19], in which 64 grams were used of material for cement and 55 grams for glass residue, while for the Blaine specific surface test [20] a sample of 3.066 g of cement and 2.086 g of glass was used.

Table 1 shows the density and fineness or specific surface of Blaine of cementitious materials, in which it can be seen that the glass residue is less dense than Portland cement, having a behavior similar to the results obtained by [21], in the case of the specific surface of Blaine, it was determined that Portland cement has a greater fineness than the glass residue, which means that the glass residue has slower hydration than the cement, reducing the generation of heat that is present in the mixture, this analysis has validity as stated in [22], since the fineness is closely related to the grain size of the particles and differs with what is described in [13].

Table 1. Density and fineness of portland cement and glass residue.

Material	Density (NTC 221)	Blaine specific surface (NTC 33)
Portland cement	2.943 g/cm^3	3634.5 cm/g
Glass waste	2.503 g/cm^3	2569.8 cm/g

3.2. Fluidity

The fluidity index is a parameter that allows us to know the manageability of the mortar mix, and in which the optimal ratio of water / cement is determined to obtain a recommended fluidity, the slurries to perform the fluidity test was made according to the experimental design, since for each mixture of dosage and different age a fluidity test was carried out according to [17].

The results obtained, which can be seen in the correlation analysis of Figure 1, indicate a progressive decrease in the value of fluidity in proportion to the increase in the percentage of incorporated glass residue; for the case of 30% substitution, the fluidity of the sample is reduced to 97.6%, compared to the standard sample (0% replacement), in which the fluidity was 115%. In the same way, this behavior was repeated with the other replacement percentages. This behavior is due to that described by [23,24], who reported a decrease in fluidity attributable to the high specific surface and angular shapes of the powder particles, which impaired the workability of the mixtures.

In the correlation analysis of Figure 1, an adjusted red line is seen, which indicates the predicted value of Y for any value of X, additionally, the blue dashed lines show the prediction interval of 90%. The graph describes a linear behavior of the analyzed variable, with a degree of correlation of 92.9%, which, as previously stated, denotes the tendency to decrease the flow rate as the percentage of substitution of Portland cement by the residue of glass.

Regarding the percentage variation of the data, as shown in Figure 2, it is observed that in the different dosages tested there is a reduction in fluidity, with respect to the standard sample, a minimum value of 2.72% for 5% of glass residue and a maximum of 13.65% for 25% glass residue [23,24], obtained similar results to those obtained, additionally [25], reported that the use of glass as sand made the mixtures more compact and hard to work; However, other authors such as [26,27] report that the replacement of cement by glass powder did not lead to changes in fluidity, however, this was not the case in this research, since fluidity was seen highly influenced by the percentage of incorporated glass residue.

3.3. Density

The calculation of the density was carried out using mortar cubes of 5 cm on each side, following the recommendations of [16] for its preparation. The data obtained is shown in Figure 3, as part of the correlation analysis performed; a growth inversely proportional to the percentage of incorporated glass residue is observed mainly. This behavior is consistent with that described by [25], who used glass residue in concrete mixtures and observed that the density of the concrete was reduced by up to 7.89% after 28 days; this was mainly due to the fact that the glass has a lower specific gravity in relation to aggregates and cement. The results obtained by [25] are comparable with the results obtained for this investigation, in which a maximum reduction in density of 5.34% was obtained with respect to the standard sample with 0% incorporation.

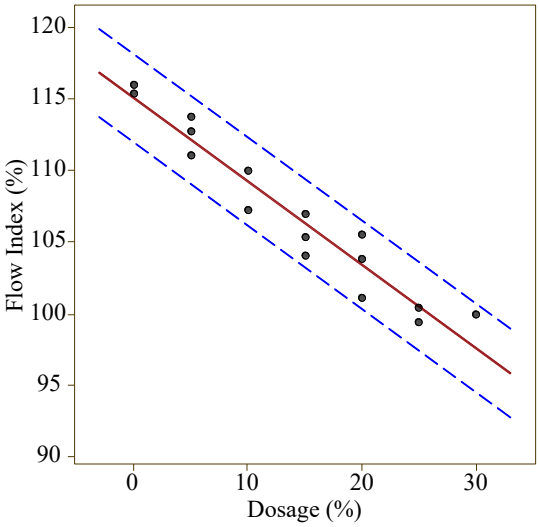


Figure 1. Linear regression for fluidity vs. dosage of glass residue.

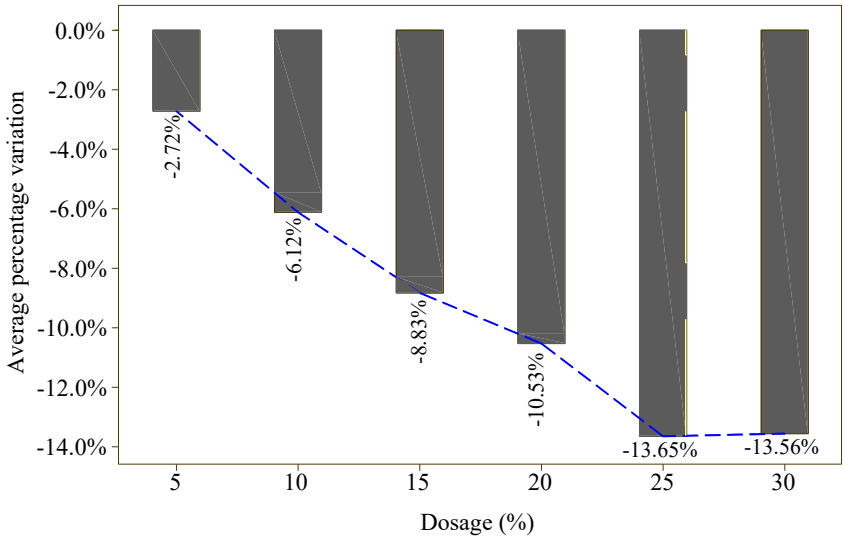


Figure 2. Average percentage difference for fluidity vs. dosage of glass residue.

In the correlation analysis of Figure 3, an adjusted red line is seen, which indicates the predicted value of Y for any value of X, additionally, the blue dashed lines show the prediction interval of 90%. The densities vary between 2.049 g/cm^3 and 1.918 g/cm^3, always maintaining a decreasing behavior which allows establishing a linear correlation to describe the analyzed variable, said correlation has a factor of 85.09% That is to say that the proposed model adjusts very well to the data.

In Figure 4 the percentage variation of the density values obtained from the different mortar mixtures with the dosages of the partial replacement of cement by glass residue is analyzed, it is evidenced that with all the densities except 25% there is a decrease progressive, with a minimum value of 1.23% for 5% of glass residue and a maximum value of 5.34% for 30%. This behavior is very useful and applicable to the recent efforts of the construction industry to achieve lighter materials. And this alternative, as [25,28-30] has already shown, allows reducing the weight of mortar and concrete since natural aggregates and the same cement have higher specific gravity than glass.

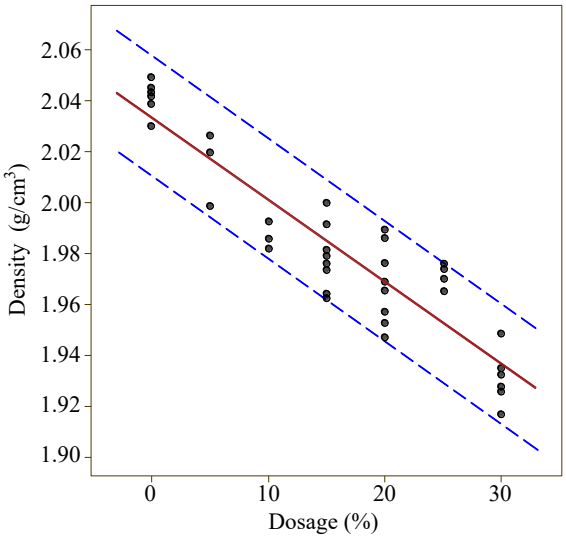


Figure 3. Linear regression for density vs. dosage of glass residue.

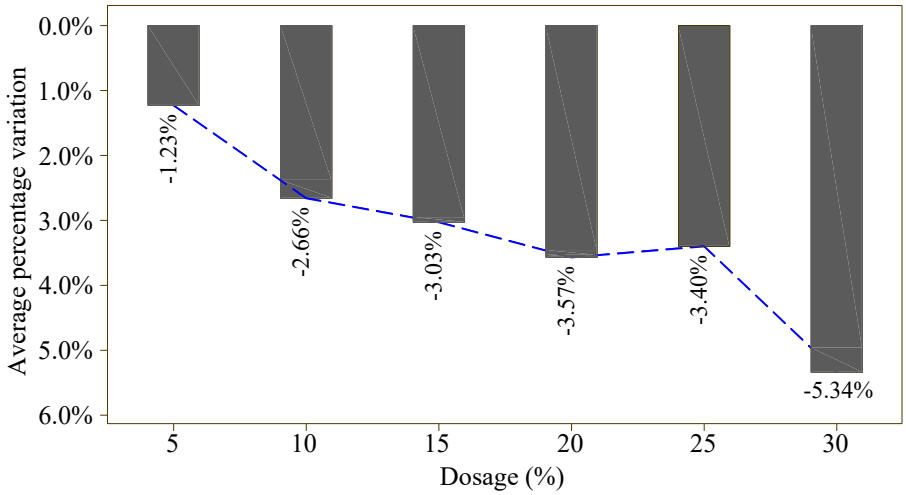


Figure 4. Average percentage difference for density vs. dosage of glass residue.

4. Conclusions

Through this investigation, the behavior of mortar mixes with substitution of Portland cement for finely ground flat glass residue was analyzed and allowed to conclude the following: (i) the density of glass residue with a particle size of less than 38 µm is 17.5% less than the density of general-purpose gray portland cement, which allows inferring that, when making mix designs based on the weight of cement, the residue glass will occupy a much larger volume than cement, (ii) the specific surface of Blaine or fineness of the pulverized glass residue is 41.43% less than that of the cement, due to the particle size, since the cement is finer, and therefore has more capacity to generate heat per hour hydration of the mix, which will make the Portland cement mix set faster than the glass residue replacement mix, (iii) the fluidity of mortar mixes with partial replacement of cement by glass residue is reduced by up to 13.65% compared to the standard mix, influencing the workability of the mortar, since a greater amount of water is required to obtain a standard consistency of 115; like the fluidity, for its part, the density of the mixture is reduced by increasing the percentage of substitution, giving a specific use to the glass residue when light mortars are required, in addition to contributing to the recycling of hazardous waste and pollutant.

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