Mechanical strength of experimental mortars for plastering with partial addition of fly ash and hydrated lime

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Abstract. In order to highlight the implementation of fly ash and hydrated lime in replacement of a % of the weight of the cementitious material traditionally used for the elaboration of mortar mixtures, a conventional mixture was made for mortars where the materials that compose this type of mixtures were previously selected, analyzed and implemented. The evaluations of the materials were carried out under the standards indicated by the Norma Técnica Colombiana that guarantee the reliability of the resulting mixture. The fly ash that was used was obtained from the power plant Termotasajero of the Municipality of San Cayetano located in the department of north Santander-Colombia. The hydrated lime was obtained in the municipality of Malaga located in the department of Santander-Colombia. The experimental mixtures presented a replacement of 40%, 50%, 60% and 70% of the weight of the cementitious material traditionally used in the city. At the same time, 10%, 20% and 30% of hydrated lime was added to the experimental mixtures in relation to the weight of the added fly ash. With each one of the elaborated mixtures, both traditional and experimental, 3 cubes were made as indicated in the Norma Técnica Colombiana for this purpose. After the 21 days of its elaboration to each one of the cubes their resistance to compression was determined by means of their respective test in the ibertest machine property of the Francisco de Paula Santander university located in the city of San Jose de Cucuta-Colombia. The data obtained in the tests were compared determining the viability of the addition of fly ash and hydrated lime in the mixtures for paste mortar, with the incorporation of a % additional water in their designs. Thus generating a positive environmental, social and economic impact through the final disposal and marketing of an industrial waste, fly ash, and the use of a natural material, hydrated lime, in mixtures with cementitious matrix for mortars.

1. Introduction
Human overexploitation of natural resources for centuries and, more recently, climate change have significantly degraded ecosystems [1], this situation, together with the remarkable increase in the world’s urban population, which has surpassed the rural population in the first decade of the twenty-first century [2], and if we add the worrying projection of the increase in world population in the next 30 years made by the united nations in 2015, estimated at approximately 9.700 million people who will inhabit the planet earth in 2050 [3], it undoubtedly becomes an alarming and worrying situation that has been the focus of global alert. Alarm that has generated an effect of collective concern causing a positive interest in the nations that, for the most part, promote internally and externally, policies that they consider to be incentives to the presented problematic. Policies that evoke an environmental
conscience in all sectors whose purpose lies in the reduction of polluting residues and the good management of the same when they originate.

The construction industry, through the incessant extraction of non-renewable resources for the direct manufacture of materials used in the execution of civil engineering works [4], has generated a negative impact, since decades ago, causing the erosion of environmental resources. Natural materials that today continue in constant extraction due to the housing demand generated by the unstoppable increase of the world population.

The mixtures of mortar and concrete made with cementitious material, stone aggregates and water, become the essential material in construction projects, whose simple elaboration and constructive advantages make them the most used construction material for the development of engineering works all over the world [5].

Innovation and research are the key to the implementation of a circular economy in the construction sector, fundamental to the sustainability of today's world [6]. Fortunately, in recent decades, the development of environmentally friendly building materials has been significantly promoted by the high sustainability standards of the construction industry [7] resulting in processes, materials and construction systems that reduce polluting residues at each of their stages of production, putting into work and execution respectively.

The innovative exploration of new construction approaches has led the construction industry towards the achievement of analysis, planning and execution of sustainable and environmentally friendly civil engineering works, a characteristic that involves aspects that not only refer to the economy of the construction projects, but also, to the environment where they are developed, it is thus, as the cultural and environmental nuance present an equal or superior value to the economic one.

The construction industry has evolved over time, and along with it, research into the raw materials it demands [8]. The research community has been carrying out research work for possible solutions to the environmental problems generated by the production of cement-based mixtures [9], inroadsing into the addition of non-conventional materials for the replacement of the elements that traditionally constitute this type of mixtures.

Fly ash (FA), an artificial pozzolana, product of the combustion of coal in the generation of energy in thermoelectric plants [10], has been the object of study in several research projects in search of its implementation as a construction material. Thus, lightweight aggregates such as FA, expanded clay, expanded perlite and pumice can be used partially or totally to replace traditional aggregates in cement mixtures [11], reaching a general conclusion where we can indicate that FA can be used as a substitute material for cement in mortar and concrete mixtures, as well as their aggregates [12].

The present research paper indicate the resistance to the compression of experimental mixtures (EM) for paste mortars to which 40%, 50%, 60% and 70% of the weight of the cementitious material was replaced by FA coming from the thermoelectric Termotasajero located in the municipality of San Cayetano-Colombia. At the same time, 10%, 20% and 30% of hydrated lime (HL) was added to each of the EM designs in relation to the weight of the same cementitious material as an additional element. The data from the EM were tabulated and compared with the resistance obtained by a standard mortar mixture, in order to determine the differences between the mechanical resistance of each of the samples.

The data obtained led to the conclusion that it is feasible to use the fly ash-lime ratio in paste mortar mixtures. Information of interest that provides results that will be of bibliographical reference in future investigations whose object of study is the partial addition of FA and HL in the mixtures with cementitious matrix used for the elaboration of plastering mortars. Additions that would contribute to a considerable reduction of cement in this type of mixtures, contributing significantly to the economy of the construction project and providing a favourable environmental factor consisting of the reduction of polluting emissions resulting from the manufacture of the cementitious material traditionally used.

2. Materials & Methods
An experimental type research was proposed, using the materials resistance laboratory of the Francisco de Paula Santander university (UFPS) based in the city of San Jose de Cúcuta-Colombia, as well as its homologous owned by the company Concretos & Morteros located in the city of San Jose de Cúcuta-Colombia. A mixture of conventional mortar (CMM) was made with a ratio of 1/2.75 where 1 indicates the proportion of cement and 2.75 the portion of sand normalized as indicated by the norma técnica colombiana 3937 (NTC 3937) [13]. A type 1 Portland cementitious (PC), material marketed by cemex company, was used and analyzed under the parameters described in NTC 121 [14].

The chemical analysis of the PC was performed under the standards described in NTC 321 [15]. The classification of the PC was carried out under NTC 30 [16]. Grinding sand from Transmateriales S.A company, located in the city of San Jose de Cúcuta-Colombia, was used, which was sieved to obtain the 20-30 ratio, properties of the normalized sand as indicated in NTC 3937. The water for mixing was selected under the standards described in NTC 3459 [17]. The water content for mixing was carried out under the indications described in NTC 111 [18] by means of the flow Table, because the EM presented combinations of PC with FA and HL, yielding an addition of water per experimental mixture (w/em).

With the mortar obtained, for the CMM, 3 cubes were elaborated according to the parameters indicated in the NTC220 [19]. After 24 hours of production, the CMM cubes were immersed in water with the characteristics and specifications given by NTC 220. The compressive strength of the 3 cubes was determined 21 days after their manufacture with the help of the ibertest machine located in the UFPS. The data from each of the cubes were analyzed, averaged and tabulated to be compared with the results from the EM.

A sample was taken of the FA, product of the combustion of the mineral coal used for the production of energy coming from the company Termotasajero of the municipality of San Cayetano located in the department of north Santander-Colombia. The characteristics of FA were taken from previous studies [8] where the chemical characterization of the FA was carried out resulting in its classification F as illustrated in Table 1.

| Characteristic                        | Value % |
|---------------------------------------|---------|
| Humidity content                      | 00.170  |
| Loss of ignition                      | 07.960  |
| Silicon oxide (SiO₂)                  | 53.210  |
| Aluminum oxide (Al₂O₃)                | 26.740  |
| Iron oxide (FeO₃)                     | 09.150  |
| Calcium oxide (CaO)                   | 00.590  |
| Magnesium oxide (MgO)                 | 00.450  |
| Sodium oxide (Na₂O)                   | 00.160  |
| Potassium oxide (K₂O)                 | 00.640  |
| Titanium dioxide (TiO₂)               | 01.280  |
| Phosphorus pentoxide (P₂O₅)           | 00.520  |
| Sulfuric oxide (SO₃)                  | 00.010  |
| Barium oxide (BaO)                    | 00.140  |
| Stroniu oxide (SrO)                   | 00.030  |
| Density                               | 02.103  |
| Combustibles                          | 07.800  |
| Classification                        | Class F |

HL type N was used from the municipality of Malaga located in the department of Santander Colombia. The HL was selected according to the standards described in NTC 4019 [20].

Based on the design of the CMM, 4 EM were made plastering mortars. 40%, 50%, 60% and 70% of the weight of the PC was replaced by FA. Each one of the EM-40, EM-50, EM-60 and EM-70, additionally HL was incorporated in 10%, 20% and 30% in relation to the weight of the FA, leaving
the ratio EM-40/10, EM-40/20 and EM-40/30, describing in the same way the others EM. For each one of the EM, 3 cubes were made which, as in the CMM, were tested for their resistance to comprehension 21 days after their elaboration, carrying out the same tabulation process executed in the CMM.

The data were compared with the Table described in the title D, chapter D3 in its Table 2 D.3.4-1 of the norma sismo resistente colombiana 2010 (NSR-10) [21], where describes the classification of the plastering mortars with their respective nomenclatures, the minimum percentage of water retention and their resistance to compression in megapascals (MPa), this last specification is the most relevant in the present research paper due to the comparisons that were made between the data thrown by the EM and the Table mentioned, which is presented below.

### Table 2. Classification plastering mortars [21].

| Mortar type | Minimum compressive strength (MPa) | Minimum water retention % |
|-------------|-----------------------------------|---------------------------|
| H           | 22.5                              | 75                        |
| M           | 17.5                              | 75                        |
| S           | 12.5                              | 75                        |
| N           | 07.5                              | 75                        |

### 3. Results

#### 3.1. Desing of experimental mixes

Analyzed the materials used in the manufacture of the CMM, a step was taken to design each one of the EM for mortar paste. These designs were made by replacing the % of the weight of the PC, indicated, by FA, and in turn, the % of the weight of the FA that was replaced, by HL.

A simple mathematical operation was performed, exemplified as follows: For the EM-40/10, it was performed: 650 g (weight of PC used for the CMM)×40%=260 g (weight of PC to be replaced); 260g×10%= 26g (weight of added HL);260 g−26 g = 234 g (weight of added FA), this and the other experimental designs are shown in the following Table 3.

### Table 3. Design of experimental mixes by % of replacement.

| Mixes | Sand (g) | Cementitious material (g) | Fly ash (g) | Hydrated lime (g) | Ratio water cementitious material |
|-------|----------|---------------------------|-------------|-------------------|----------------------------------|
| CMM   | 1,787.5  | 650                       | 000.0       | 000.0             | 0.485                            |
| EM-40/10 | 1,787.5  | 390                       | 234.0       | 026.0             | 0.800                            |
| EM-40/20 | 1,787.5  | 390                       | 208.0       | 052.0             | 0.800                            |
| EM-40/30 | 1,787.5  | 390                       | 182.0       | 078.0             | 0.770                            |
| EM-50/10 | 1,787.5  | 325                       | 292.5       | 032.5             | 0.775                            |
| EM-50/20 | 1,787.5  | 325                       | 260.0       | 065.0             | 0.750                            |
| EM-50/30 | 1,787.5  | 325                       | 227.5       | 097.5             | 0.750                            |
| EM-60/10 | 1,787.5  | 260                       | 351.0       | 039.0             | 0.750                            |
| EM-60/20 | 1,787.5  | 260                       | 312.0       | 078.0             | 0.750                            |
| EM-60/30 | 1,787.5  | 260                       | 273.0       | 117.0             | 0.725                            |
| EM-70/10 | 1,787.5  | 195                       | 409.5       | 045.5             | 0.775                            |
| EM-70/20 | 1,787.5  | 195                       | 364.0       | 091.0             | 0.775                            |
| EM-70/30 | 1,787.5  | 195                       | 318.5       | 136.5             | 0.775                            |

#### 3.2. Compressive strength of experimental mixes

Once the cubes had been elaborated, 3 for each one of the EM, their mechanical resistance was determined in MPa, after 21 days of immersion setting. The cubes were identified under the nomenclature; Sample 1 (S-1), Sample 2 (S-2) and Sample 3 (S-3) for each one of the cubes made respectively, to then be tested in the universal machine ibertest located in the material resistance laboratory of the UFPS. Having the results of each of the cubes tested, they were tabulated and averaged as indicated in the following Table 4.
Table 4. Test of compressive strength of mortar cubes to the 21 days.

| Mixes   | Compressive strength in megapascals | Average value |
|---------|-------------------------------------|---------------|
|         | S-1       | S-2       | S-3       |               |
| CMM     | 8.32      | 8.35      | 8.45      | 8.37          |
| EM-40/10| 7.40      | 7.36      | 7.47      | 7.41          |
| EM-40/20| 6.43      | 6.40      | 6.60      | 6.48          |
| EM-40/30| 8.23      | 8.10      | 8.20      | 8.18          |
| EM-50/10| 6.76      | 6.68      | 6.75      | 6.73          |
| EM-50/20| 5.46      | 5.68      | 5.65      | 5.60          |
| EM-50/30| 6.10      | 6.08      | 6.10      | 6.09          |
| EM-60/10| 3.75      | 3.88      | 3.80      | 3.81          |
| EM-60/20| 4.45      | 4.53      | 4.55      | 4.51          |
| EM-60/30| 4.14      | 4.10      | 4.11      | 4.12          |
| EM-70/10| 4.18      | 4.25      | 4.18      | 4.20          |
| EM-70/20| 3.42      | 3.37      | 3.38      | 3.39          |
| EM-70/30| 3.50      | 3.52      | 3.55      | 3.52          |

3.3. Comparison of resistances mixture of conventional mortar vs experimental mixtures
For better visualization and identification of the data obtained, comparative bar images were made where the resistance of the EM can be quickly compared with that acquired by CMM. In the following figures it is possible to visualize in the upper part of the bars the resistance obtained to compression in MPa after 21 days and in the lower part the design of mixture that represents each one of them.

Figure 1 shows the compression resistances obtained by the EM-40 and their comparison with the CMM, where it is possible to identify the little difference between the EM-40/30 and the CMM which only represents 0.19MPa. As for the resistance obtained by the EM-40/10 its comparative difference yielded 0.96MPa, being a difference not so representative. With respect to the EM-40/20, a comparative gap of 1.89MPa was presented, this being the lowest resistance obtained by the EM-40.

Figure 2 shows the differences in compression strength obtained by EM-50 compared to CMM, where EM-50/10 was 1.64MPa below the comparative strength of CMM, EM-50/30 achieved a difference of 2.28MPa, while EM-50/20 obtained the lowest strength for this EM design with 2.77MPa.

Figure 1. Resistance to compression in megapascals of the mixture of conventional mortar and experimental mixes-40.

Figure 2. Resistance to compression in megapascals of the mixture of conventional mortar and experimental mixes-50.

Figure 3 allows us to identify the mechanical resistances thrown by the EM-60 and their comparison with the CMM, which clearly reveals their considerable comparative gap which averages 4.22MPa.
Figure 4 shows that the average of the comparative gap in mechanical resistance exceeds 4.60MPa in the 3 EM, making it the EM with the lowest mechanical resistance obtained.

4. Conclusions

It was found that the ratio of 0.485 of water cementitious material presented very little manageability and a high porosity, due to the low amount of water added, a characteristic that reduced the compressive strength of the cubes made with CMM. Preliminary evidence from the fluidity test showed that the relative amount of HL with respect to the entire PC, as it increases, generates a reduction in the % of water added to reach 110%±5% fluidity as indicated by the NTC. Only in the case of the 70% replacement of the PC by FA and HL EM-70, it is evidenced that the fluidity is stable and in addition in this percentage of replacement it is noted that it does not follow the tendency of the decrease of the necessary amount of water, since even more water was required than in the mixtures with 50% and 60% replacement. The EM-40/30 obtained the compressive strength closest to the values indicated by the CMM, while the EM-70/20 had the lowest values. For further research, consideration should be given to the inclusion of a greater percentage of water in the process of both CMM and EM in order to improve their mechanical behaviour, in this way the data would be equal to or approximate to those indicated by the respective standards. With the improvement in the water additions in the EM that include FA and HL in replacement of PC in mortar mixtures, the expected behavior of this type of mixtures for later use in construction works would be guaranteed. The mechanical resistance ranges reached by the EM-40 indicate the viability of the combination of FA and HL to replace the PC traditionally used in different civil engineering works, a fact corroborated by the comparison of the results with Table 2 where the resistance of the EM-40/30 is classified in a N-type paste mortar used in systems with minimum energy dissipation capacity in the inelastic range.

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