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To cite this article: O Hurtado-Figueroa *et al* 2019 *J. Phys.: Conf. Ser.* **1386** 012085

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# Influence of water/cement ratio on mechanical strength of concrete with partial addition of fly ash and hydrated lime

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**Abstract.** Three mixtures were made for conventional concrete with different additions of cement, 300 kg/m<sup>3</sup>, 350 kg/m<sup>3</sup> and 400 kg/m<sup>3</sup>, being these the 3 designs of mixtures more used for the elaboration of simple concretes. For each of the conventional mixtures, the % of water used for mixing was varied, which constituted 60%, 65% and 70% of the weight of the cementitious material. These % were taken in gradual increase to the one traditionally used in each of the mixing designs made. The aggregates used were assigned by Transmateriales S.A, located in the city of San José de Cúcuta, Colombia. The analysis of the materials of the mixtures, were carried out under the standards of the “Normas Técnicas Colombianas” and the Tests of the “Instituto Nacional de Vías”. 40% of the concrete mix cementitious material was replaced by fly ash and hydrated lime. In order to determine the mechanical behavior of the mixtures resulting from partial addition. The ash was collected from the thermoelectric Termotasajero S.A, located in the city of San José de Cúcuta, Colombia. The hydrated lime was recovered from the municipality of Malaga located in the department of Santander, Colombia. Of the % of cementitious material replaced, 30% corresponded to lime and 70% to ash, as an experimental basis for the production of unconventional mixtures. Having the % of cementitious material to replace and the % of substitute material, 3 designs of experimental mixtures were made taking as base each one of the designs of conventional mixtures made, with equal % of water for its mixing. Twenty-seven cylinders were manufactured for the experimental mixtures and the same number for conventional mixtures, a figure that corresponded to the production of 3 specimens per % of water added in each of the established mixture designs. The compressive strength of the cylinders made in the materials resistance laboratory of the Universidad Francisco de Paula Santander, San José de Cúcuta, Colombia was tested. It was concluded in the influence of the % of water in the mechanical resistance of the experimental mixtures and the viability of the use of this type of mixtures in the elaboration of nonstructural concretes, data of importance with which the construction costs would be reduced considerably, generating in turn, a positive environmental impact by means of the inclusion of residual materials in the concrete mixtures.

## 1. Introduction

Temperature increase and excessive rainfall are some of the factors that manifest themselves indicating the transformation of the atmospheric system [1]. This alteration causes a disorder in the biological clock of the ecosystems, causing considerable damage in the different economic sectors.

The civil engineering works whose main characteristic has been the notorious use of natural elements for their direct or indirect implementation in the development of construction projects, in recent years, has taken on the task of seeking ecologically sustainable alternatives that curb the



emission of contaminating residues in the processes inherent in obtaining, preparing and putting in place the construction materials [2] necessary for the execution of construction work.

This exploration, led by civil engineering professionals in their eagerness to obtain innovative alternatives and technological development for the innovation of materials that considerably reduce emissions and waste [3] throughout the construction cycle of civil works, in accordance with the environmental regulations of their country of origin, is undoubtedly a call that requires research intervention as an element that helps meet the challenge.

For this reason, at a global level, research has been carried out to improve processes and construction materials that eliminate emissions of pollutants elements [4]. Some of these research projects take as object of study industrial waste, notably pollutants, which are not given a proper management in their final disposal.

Portland cement-based mixes such as mortar and concrete, due to their composition that compromises the use of non-renewable natural materials such as natural stone aggregates (NSA), fine and coarse [5] from quarries or alluvial terraces, are currently being studied in research projects that seek the total or partial replacement of some element that is part of mix.

The physical-chemical characteristics of the materials analyzed are key to replacing those traditionally used in mortar and concrete mixtures. Thus, fly ash [6], lime [7], glass [8], iron filings [9], slag [10], expanded polystyrene [11], treated hospital waste [12], shredded ceramic waste [13], demolition waste [14], pieces of tires [15], among others, become alternative materials for the replacement of portland cement (PC) and NSA traditionally used in this type of mixtures.

The present research paper describes the compressive strength of experimental concrete mixtures (ECM) which were partially replaced by fly ash in % of the weight of the PC. At the same time, each one of the ECM was added hydrated lime that replaced a % of the weight of the added fly ash. The resistances obtained, after 28 days of immersion setting, were verified with those thrown by the conventional concrete mix (CCM) that served as a comparative basis. Comparisons were analyzed and tabulated. With the data obtained, the viability of using this type of non-conventional aggregate for non-structural concrete mixtures was concluded. This would lead to the use of non-conventional materials in the elaboration of mixtures for concrete, generating a positive economic, environmental and social impact consisting of the correct final disposal of a residual material as a partial replacement of the cementitious material traditionally used in the elaboration of concrete mixtures, a situation that considerably influences the reduction of construction costs destined to the purchase of the cementitious material. As far as social impact is concerned, it is inherent to the environmental impact since it would be enjoyed of environments that are more free of pollution due to the reduction of polluting gases coming from the manufacture of cement.

## 2. Materials and methods

An experimental type investigation was proposed by means of the accomplishment of concrete cylinders testing of 100 mm of diameter and 20 mm of height for each one of the mixtures of concrete realized, CCM and ECM. Three types of CCM were carried out to which the quantity NSA, PC and water were calculated for the elaboration of 1  $m^3$  of concrete. Each one of the 3 CCM had a different amount of cement in Kilograms (kg) incorporated, taking as a reference the most used simple concrete mixtures. In this way it was established that the CCM-300 was the mixture to which 300 kg of PC were incorporated for the elaboration of 1  $m^3$  of concrete. The other mixtures were identified in the same way, with a gradual increase of 50 kg in the quantity of PC used for its elaboration, yielding a variable indicator. Establishing CCM-350 and CCM-400.

For the preparation of the CCM, PC type 1 from cemex brand general application was used. As indicated by the "Norma Técnica Colombiana (NTC)", the physical and mechanical specifications of the PC were analyzed under the parameters indicated by NTC121 [16]. The chemical analysis of the PC was carried out with the methods indicated in NTC321 [17]. The classification of the PC was carried out in accordance with NTC30 [18].

The NSA was taken from Transmateriales S.A, a company located in the city of San José de Cúcuta, Colombia. 6400 g of coarse aggregate and 1960 g of fine aggregate were used. NSA sizes were identified based on NTC77 [19]. Unit mass and voids between NSA particles were catalogued according to NTC92 [20]. The lengthening and flattening indices of the coarse NSA were determined with the help of Test 230 of the instituto nacional de vias (INV E230) [21]. The NTC237 [22] was used as the basis to identify for the density and absorption data of the fine NSA. Density and absorption of coarse NSA were indicated by NTC176 [23]. The determination of the wear of the coarse NSA was carried out under that described in NTC98 [24].

The fly ash (FA) used for the elaboration of the ECM was taken from the Termotasajero S.A power plant located in the city of San José de Cúcuta, Colombia. The physico-chemical characteristics of the FA were appropriate from previous studies. The hydrated lime (HL) implemented in the ECM was brought from the Municipality of Malaga in the department of Santander, Colombia. The S type classification of the HL was identified under NTC4019 [25]. The water used in the CCM and ECM mixtures met the parameters described in NTC3459 [26].

Based on the CCM, 40% of the weight of the PC was replaced by FA which in turn was replaced 30% of their weight by HL. For each of the CCM, 3 ECM were carried out to which the water content was differentiated. The amount of water added to the ECM was in the range of 60%, 65% and 70% as a result of the water/cementing material (a/mc) ratio for each of the ECM. Identified as ECM-300/60, ECM-300/65 and ECM-300/70 in the mixture with a content of 300 kg of PC, relation that was used for the others ECM. With each one of the variations in the amount of water incorporated in the ECM, 3 test cylinders were made in order to average data. This was identified as ECM-300/60<sup>a</sup>, ECM-300/60<sup>b</sup> and ECM-300/60<sup>c</sup> for the mixture containing 300 kg of PC and whose a/mc ratio is 60%. The others ECM were identified in the same way with their respective PC quantity and a/mc ratio.

A total of 54 cylinders were made, 27 for the CCM that were the comparative basis, and an equal number for the ECM with their respective a/mc ratios. Its resistance to compression was tested in the ibertest machine located in the materials resistance laboratory of the Universidad Francisco de Paula Santander (UFPS) in the city of San Jose de Cúcuta, Colombia. The averaged data were tabulated to perform the comparative analysis between the resistance obtained by the CCM vs ECM.

Table 1 and Table 2 present the results of the granulometric tests of the aggregates, coarse and fine, respectively, used for the elaboration of the CCM and ECM.

**Table 1.** Aggregate granulometry coarse.

Sieve	Opening (mm)	Soli mass retained	% Retained	% Cumulative retained	% Pass
1"	25.40	0000.0	00.000	00.000	100.000
3/4"	19.00	0000.0	00.000	00.000	100.000
1/2"	12.70	1396.0	21.183	21.813	78.188
3/8"	09.50	2053.0	32.078	53.891	46.109
No 4	04.76	1769.0	27.641	81.531	18.469
No 8	02.38	960.0	15.000	96.531	03.469
No 16	01.19	214.0	03.344	99.875	00.125

**Table 2.** Aggregate granulometry fine.

Sieve	Mass (g)	% Retained	% Cumulative retained	% Pass
3/8"	000.0	00.000	00.000	100.0
No 4	125.5	06.403	06.403	93.60
No 8	256.9	13.107	19.510	80.49
No 16	446.3	22.770	42.281	57.72
No 30	392.4	20.020	62.301	37.70
No 50	371.4	18.949	81.250	18.75
No 100	255.4	13.031	94.281	05.72
No 200	096.5	04.923	99.204	00.80
Fund	015.6	00.796	100.00	00.00

### 3. Results

#### 3.1. Design of experimental mixes

After the analysis of the materials and the subsequent elaboration of the CCM, the design of the 3 ECM was proceeded. As a practical example it is argue that for the CCM-300, initially 40% of the PC that was replaced was identified with a simple mathematical operation a  $300 \text{ kg} \times 40\% = 120 \text{ kg}$ . Then it was described the weight of the FA which constituted 30% of the total weight of the PC to replace  $120 \text{ kg} \times 30\% = 36 \text{ kg}$ , giving the value of the weight of FA to use which corresponded to 36 kg. In order to know the weight of the FA to incorporate, the weight of the HL was subtracted from the value obtained after calculating 40% of the PC to be replaced, method by which the weight of the FA to incorporate to each one of the ECM was detailed  $120 \text{ kg} - 36 \text{ kg} = 84 \text{ kg}$  thus knowing the data of the weight of the FA to be used 84 kg. The same dynamic was carried out with each of the PC weights in the others CCM. The relationship a/mc was highlighted. Following the practical example, for the ECM-300 whose PC weight corresponded to 300 kg it was indicated that  $300 \text{ kg} \times 60\% = 180$  liters of water (l), where it was obtained that for the ECM-300/60 the quantity of water to use for the elaboration of  $1 \text{ m}^3$  of concrete is 180l. 27 ECM were made, which presented the same % PC to be replaced according to their weight and the a/mc ratio.

Table 3 presents the ECM carried out, showing each of the assigned nomenclatures with their respective % and quantities of both traditional and non-conventional materials. Also shown is the a/mc for each of them.

**Table 3.** Design of experimental mixes.

ECM	1/m <sup>3</sup>		% Volume		kg/m <sup>3</sup>			PC	FA	HL
	a/mc	Water	Air	NSA/m <sup>3</sup>	Total mass NSA	Mass NSA coarse	Mass NSA fine			
ECM-300/60	0.60	180.0	2%	66.72%	1775.58	887.79	887.79	180	84.0	36
ECM-300/65	0.65	195.0	2%	65.22%	1735.66	867.83	867.83	180	84.0	36
ECM-300/70	0.70	210.0	2%	64.47%	1715.70	857.85	857.85	180	84.0	36
ECM-350/60	0.60	210.0	2%	63.25%	1683.40	841.70	841.70	210	98.0	42
ECM-350/65	0.65	227.5	2%	61.50%	1636.82	818.41	818.41	210	98.0	42
ECM-350/70	0.70	245.0	2%	59.75%	1590.26	795.13	795.13	210	98.0	42
ECM-400/60	0.60	240.0	2%	58.29%	1551.30	775.65	775.65	240	112.0	48
ECM-400/65	0.65	260.0	2%	56.29%	1498.06	749.03	749.03	240	112.0	48
ECM-400/70	0.70	280.0	2%	54.29%	1444.84	722.42	722.42	240	112.0	48

#### 3.2. Compressive strength of conventional concrete mix and experimental concrete mix

For the comparative analysis between the resistances of the CCM and the ECM, an equal number of test cylinders were made with the CCM, following the same a/mc ratio that the ECM presented.

Table 4 and Table 5 present the average compressive strengths of ECM and CCM, with each a/mc incorporated. The mechanical tests of the samples were carried out after 28 days of immersion in water according to the tolerance of admissible time for testing concrete specimens described in NTC673 [27].

#### 3.3. Resistance comparison compression of conventional concrete mix vs experimental concrete mix

Figure 1 shows the resistance obtained by the CCM and ECM-300 after 28 days, the colors of the bars identify each of the mixtures and the number on them indicates the resistance to compression obtained in megapascals (MPa). The superiority of CCM over ECM substantial. The CCM doubled the value obtained by the ECM. The ECM-300/60 obtained the highest resistance compared to the others ECM. It was also noted that the differences in the a/mc ratio between CCM-300/65 and CCM-300/70 had a minimal effect on their mechanical behavior. The differences between the ECM-300/65 and ECM-300/70 presented the same characteristic.

**Table 4.** Test of resistance to the compression of experimental concrete mix at 28 days.

Experimental concrete mix	Averaged value	
	Strain kilonewton	Resistance megapascals
ECM-300/60	56.12	07.13
ECM-300/65	41.15	05.24
ECM-300/70	45.02	05.77
ECM-350/60	83.00	10.56
ECM-350/65	64.01	08.15
ECM-350/70	71.08	09.04
ECM-400/60	87.28	11.08
ECM-400/65	73.35	09.34
ECM-400/70	73.07	09.30

**Table 5.** Test of resistance to the compression of conventional concrete mix at 28 days.

Conventional concrete mix	Averaged value	
	Strain kilonewton	Resistance megapascals
CCM-300/60	129.99	15.14
CCM-300/65	116.90	14.88
CCM-300/70	115.62	14.72
CCM-350/60	147.16	18.73
CCM-350/65	146.59	18.66
CCM-350/70	141.22	17.98
CCM-400/60	211.04	26.87
CCM-400/65	191.64	24.40
CCM-400/70	175.14	22.30

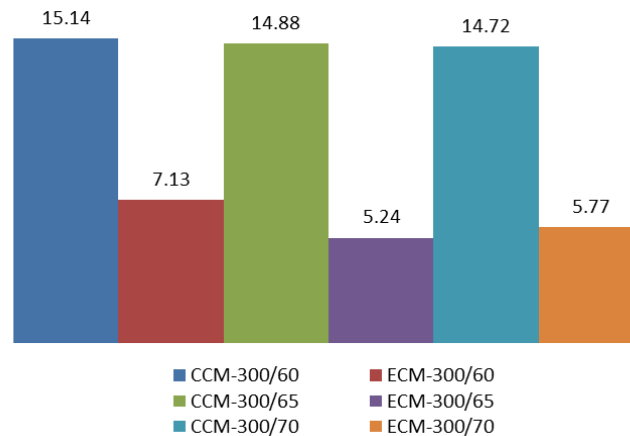
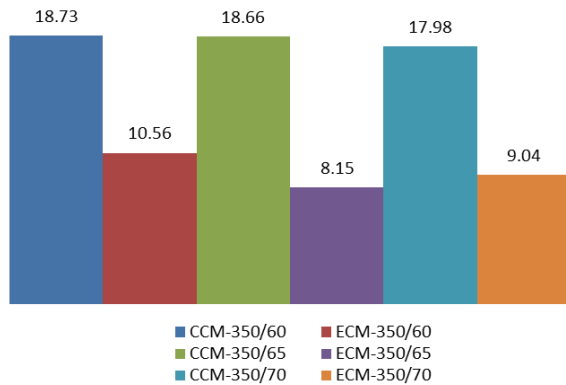
**Figure 1.** Resistance to compression in megapascals at 28 days of the conventional concrete mix and the experimental concrete mix -300.

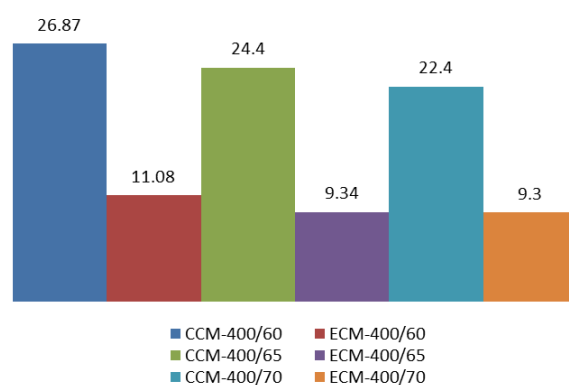
Figure 2 represents the differences in resistance marked by the CCM over the ECM. This time the CCM-350/65 only doubled its result over the ECM-350/65. The ECM-350/60 although it presented a low resistance compared to the CCM-350/60, reduced the gap compared to the other ECM. The difference in the a/mc ratio of CCM-350/60 and CCM-350/70 is slightly less than 1 MPa. The same difference understood by the ECM-350/60 and ECM-350/70 reached just over 1.5 MPa.

Figure 3 continues the superiority in mechanical resistance of the CCM over the ECM. The percentage of water added affects the resistance of the CCM with a difference of 4.47MPa between the CCM-400/60 and the CCM-400/70. The amount of water added in relation to the CCM is 15% which generates 40l of additional water for the preparation of  $1m^3$  concrete. The a/mc ratio between the ECM-400/60 and the others ECM-400 generated a little more than 1.7 MPa in its mechanical

resistance. The resistances between the ECM-400/65 and ECM-400/70, even with their different a/mc ratio, were minimal.



**Figure 2.** Resistance to compression in megapascals at 28 days of the conventional concrete mix and the experimental concrete mix -350.



**Figure 3.** Resistance to compression in megapascals at 28 days of the conventional concrete mix and the experimental concrete mix -400.

#### 4. Conclusions

The percentage of PC replacement in all CCM generated that the compressive strength of almost all ECM was below 50% of the values obtained by CCM. The a/mc ratio, in general, did not generate much difference between the mechanical behavior of both the CCM and the ECM. The average resistance gap obtained by ECM-300/60, ECM-350/60 and ECM-400/60 in comparison with ECM-300/65, ECM-350/65 and ECM-400/65, was 2.01MPa, while the gap obtained by ECM-300/65, ECM-350/65 and ECM-400/65 in relation to ECM-300/70, ECM-350/70 and ECM-400/70 was 0.49 MPa, with a special characteristic which lies in the increase in resistance of the mixtures with a higher ratio a/mc. In this last comparison the influence of the added water in the resistance of the ECM is denoted, with which it was possible to identify that in the face of rising of the % of incorporated water greater is the obtained mechanical resistance. Conclusion that would give way to new investigations on the use of FA and HL in partial replacement of PC in concrete mixtures, starting with the progressive increase in the ratio a/mc starting with the ratio a/mc 70%. Although the mechanical resistances reached by the ECM were low, in comparison with the CCM, the inclusion of the FA and the HL in partial replacement of the PC in concrete mixtures is not ruled out, since this type of non-conventional mixtures can be used for the elaboration of elements in non-structural concrete, such as low resistance concretes and floors, concretes that are also necessary for the execution of the different works of civil engineering, where a final disposition would be given to a residual material product of the combustion of the mineral coal, as it is the case of the FA.

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