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Resistance to compression of conventional concrete alleviated through partial substitution of coarse aggregate for expanded polystyrene

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Abstract. A conventional concrete mix was elaborated using the Colombian Technical Standards NTC and Title C of the NSR-10 that rule in Colombia. 10 and 20% of the coarse aggregate volume was replaced with expanded polyethylene, 2 experimental mixes were elaborated with each of the incorporated %. 3 mixing cylinders were made, each one with the elaborated mixes to test their resistance to compression on days 7, 14 and 28. The obtained data in the tests performed on the material resistance laboratories from the UFPS (University Francisco de Paula Santander) showed the mechanical behavior regarding the resistance to compression of conventional and experimental concrete mixes at different concrete ages. The results of this research conclude that although there is a minimum resistance superiority in conventional concrete, the experimental mixes are viable for implementation in engineering projects.

1. Introduction

The construction advantages that concrete offers make it the most implemented construction material for the development of engineering works worldwide, only by looking at our surroundings we can find many structures elaborated with this material.

Concrete, commonly made with cement, aggregates and water, is currently the most used material created by men [1], its versatility, along with its economy and easy preparation and application are the characteristics that give concrete the first place on the list when planning a construction project. The usage of non-renewable natural materials in the design of concrete mixes, such as mineral aggregates, has caught the attention of researchers that develop research projects seeking for the replacement of mineral aggregate for ecological alternatives such as the implementation of waste material from industrial processes, domestic waste, recycled demolished material, etc.

Industrial waste and recycled materials are being used in the construction industry to preserve the environment, save materials and increase the durability of the construction material [2], it is a world tendency. The replacement of both coarse and fine aggregates in concrete mixes has generated diverse research projects that enforce its state of the art. Innovation and research are key elements for the implementation of a circular economy in the construction area, since it's fundamental for the sustainability of the world [3].

The implementation of ecological materials of low environmental impact in engineering works is the premise for the professionals in this field, who have the job of innovating designs, techniques and construction materials in modern habitational projects. For the last decades, the development of green construction materials has been significantly promoted by the highest sustainability standards in the construction industry [4], this development has positively promoted environmental consciousness on the construction workers, giving space for experimentation and implementation of innovative materials replacing the conventional ones, which in other times, might have been denied.

Expanded polystyrene (EPS) is a thermoplastic material typically of white color with closed pores. It can be used in various industrial fields, especially in package and insulating materials. This material is disposed after its one time use and its decomposition is difficult with natural means [5].

The EPS is mainly used in the packaging industry. A great quantity of EPS is disposed as waste in landfills. As we know, EPS waste is a light material, therefore, natural fine and coarse aggregates can be partially substituted by EPS for the production of concrete mixes [6].

This research project evidenced compression resistance of lightweight concrete (LC) through the elaboration of two concrete mixes with additions of 10% and 20% of expanded polyethylene for the partial replacement of natural coarse aggregate, simultaneously a comparative analysis for the results obtained in the tests for the conventional concrete mix (CCM) and two designs of LC experimental mixes was performed.

2. Materials and methods

A CCM was elaborated, for its elaboration Portland cement type 1 was used, classified according to the parameters described in the Colombian Technical Standard NTC30 [7], its chemical analysis was performed subject to the standard NTC184 [8], the cement also met with the specifications described on NTC121 [9], the aggregates were evaluated according to the guidelines described on standard NTC174 [10], its sieving was performed under the standard NTC32 [11], the test method for sieving was performed according to the standard NTC77 [12], and its densities were established following the described on standard NTC176 [13] and 237 [14]. The water used for the mixing of the concrete met with the parameters indicated by the standard NTC3459 [15]. The methodology applied was performed under the conceived in Title C "Structural concrete" on the Earthquake Resistant Standard NSR10 [16] that rules in our country. Three mixing cylinders were made with the CCM, past 7, 14 and 28 days, the resistance to compression was evaluated in the universal machine IBERFEST belonging to the material resistance laboratory in the University Francisco de Paula Santander (UFPS), Cucuta, Colombia.

The ESP was recollected from electro domestic packaging waste. Two experimental mixture designs were made, where the ESP replaced 10% and 20% of the volume from the coarse aggregate used for the elaboration of the CCM. The process of design for LC mixes was supported by the method ACI211-1 [17] which had an experimental variable with partial % application of ESP. For each design of experimental mix, 3 mixing cylinders were made and went under the same procedure described for the CCM cylinders.

The results of resistance obtained in the applied tests to the design of the CCM and the two experimental mixes, in each of the concrete ages, were analyzed and compared, concluding data of interest. The research was described as experimental through the elaboration of non-conventional mixes that were subjected to load bearing tests to evaluate their compression resistance.

2.1. Diseño de mezcla para el concreto convencional CCM

A CCM was developed with local materials. The materials were analyzed in the UFPS materials laboratory, the mixture design was the result of the tests carried out on the materials as stipulated in Title C of NSR10 (Table 1).

The analysis of the physical-mechanical properties of the EPS (Table 2) were taken from the data sheets of EPS base products, commercialized by the Venezuelan company Grupo Isotex.

Table 1. Mix design for $1m^3$ of conventional concrete.

Material	Density (g/cm^3)	Humid weight (Kg/m^3)	Volume for $1m^3$
Cement	3.1	396.15	0.127
Fine aggregate	2.42	681.57	0.281
Coarse aggregate	2.5	924.33	0.369
Water	1	238.32	0.238

The EPS was first used as an aggregate for concrete in 1957. It is the most known core material for its low density and high capacity of thermal insulation. Differing from the limited sources of lightweight mineral aggregates, the EPS aggregates are commercially available throughout the world. Therefore, concrete with EPS aggregate can be considered as an alternative for concrete with lightweight mineral aggregates [18].

Table 2. Physical-mechanical properties of expanded polystyrene.

Physical Property	Standard test	Unit	Results of the test		
Apparent minimum density	DIN 53420	Kg/m^3	15	20	30
Type of construction material	DIN 4102			B1	
Thermic conductivity (measured at -10°C)	DIN 52612	W/m°C	0.036-0.038	0.033-0.036	0.031-0.035
Tension compression with deformity of 10%	DIN 53421	Kg/cm^2	0.6–1.1	1.1–1.6	2.0–2,5
Permanent resistance to compression with <2% deformity		Kg/cm^2	0.15–0.25	0.25–0.40	0.45–0.60
Flexibility resistance	DIN 53423	Kg/cm^2	0.6-3.0	1.50–3.9	3.3–5.7
Shear resistance	DIN 53427	Kg/cm^2	0.8–1.3	1.2–1.7	2.1–2.6
Traction resistance	DIN 53430	Kg/cm^2	1.1–2.9	1.7–3.5	3.0–4.8
Elasticity modulus (compression tests)	DIN 53457	Kg/cm^2	16-52	34-70	77–113
Instant lasting non-deformity to heat with 5000 N/m2	DIN 53424	°C	100	100	100
	DIN 18164	°C	80-85	80-85	80-85
Lasting with 20000 N/m2 80-85	DIN 18164	°C	75-80	80-85	80-85
Linear thermal expansion coefficient		1/°C	$5\text{-}7x10^{-5}$	$5\text{-}7x10^{-5}$	$5\text{-}7x10^{-5}$
Specific heat	DIN 4108	W/Kg°C	0.52	0.38	0.26
Absorption of immersing water					
Day 7	DIN 4108	%	0.5-1.5	0.5-1.5	0.5-1.5
Day 28	DIN 418	%	1-3	1-3	1-3
Permeability to water vapor	DIN 52615	g/m^2d	40	35	20
Resistance index to water vapor diffusion	DIN 4108	1	20/50	30/70	40/100
					1.163W/m°C=1Kcal/hm°C $0.1N/mm^2=1Kgf/cm^2$

2.2. Design of lightweight concrete mix

The designs for the experimental mixes for the LC contemplated the elaboration of 2 mixtures intervening the design of the CCM. On the first experimental mix (EM+10) 10% of the CCM coarse aggregate volume was replaced with EPS. The second mix (EM+20) replaced 20% of the CCM coarse aggregate was replaced, following the described on the elaboration of the first mix (Table 3).

Concrete is a representative construction material, various types of materials for concrete exist according to the specific purposes, as well as high performance concrete, self-compacting concrete and lightweight concrete. Particularly, lightweight concrete or lightweight aggregate concrete, is a concrete with a density significantly lower than the conventional concrete and its amply used for isolating and structural purposes [19].

Table 3. Substitution of coarse aggregate for expanded polyethylene in 1m^3 of conventional concrete mix

Mix	% EPS	Volume (m^3)
CCM	-	-
EM+10	10	0.0369
EM+20	20	0.0738

3. Results

The result from the compression test performed at day 7, demonstrated the superiority of the EM+10 for bearing vertical loads. The mix EM+20 demonstrated the lowest resistance to the same load, compared to the CCM (Figure 1).

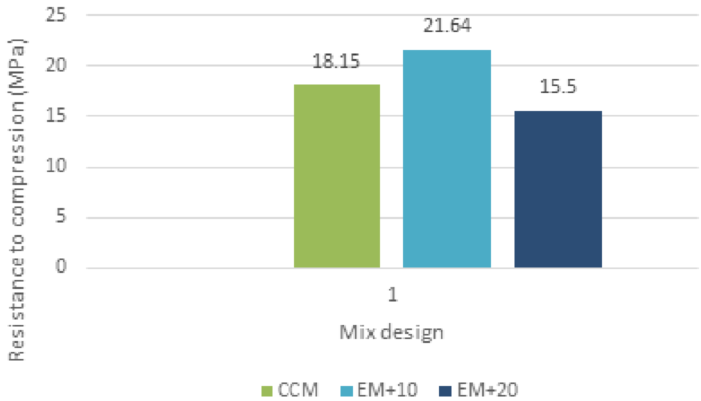

Figure 1. Resistance to compression day 7.

The data obtained in the compression test performed on day 14 (Figure 2) evidences an advantage of loading for the mix EM+10. The gap that separates the resistance obtained by the EM+10 with respect to the CCM is minimal, with only 1.33Megapascals (MPa). The EM+20 is the mix with the lowest resistance to loads.

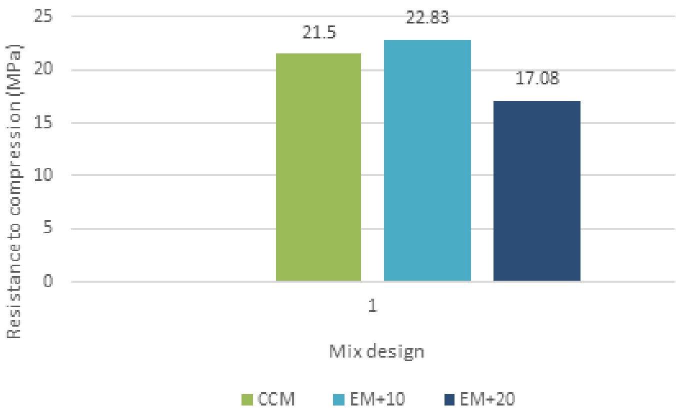

Figure 2. Resistance to compression day 14.

At day 28 the results showed data of interest (Figure 3), where the CCM surpasses the resistances supported by the EM mixes, the advantage taken by the CCM with respect to the EM+10 is not of great importance, with only a 2.58MPa difference. The EM+20 was the design with the least resistance.

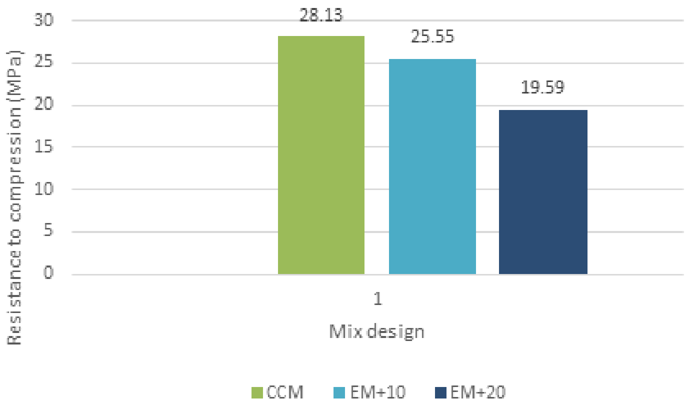

Figure 3. Resistance to compression day 28.

4. Conclusions

The importance of the environmental, economic, technical and durability aspects have caused the growth and development of LC. Until now, different methods have been introduced for the production of LC. The CCM design surpassed the resistance of the experimental mixes, which put on evidence, the mechanic characteristics of the most implemented material in engineering works. The EM+10 demonstrated high resistance obtained in early ages with respect to the CCM, characteristic that makes it reliable for its usage in architectural projects. The EM+20 was characterized by its low resistance presented in the tests performed, however, this EM design could be improved with the incorporation of some type of additional experimental aggregate, since its average difference with respect to the CCM was of 5.23MPa. Given the compression resistance results, it could be concluded that some of the causes for not reaching the design resistance could be the low density of EPS, as well as the replacement percentages of the coarse aggregates. The research work presented data of interest through the implementation of a waste material added to concrete mixes, which could give a great final disposition through its reutilization as construction material.

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