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Mechanical behavior of low density concrete mixtures with thermally expanded clay from the metropolitan area of Cúcuta

Comportamiento mecánico de mezclas de concreto de baja densidad con arcilla expandida térmicamente del área metropolitana de Cúcuta

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ABSTRACT

In order to develop construction materials with greater efficiency and performance than conventional materials, mixtures of lightweight concrete (LWC) made from thermally expanded clay (TEC) have been generated. In this article we study the mechanical properties (equilibrium density, compressive strength) of the LWC mixtures produced with raw material from the metropolitan area of Cúcuta, contrasting their characteristics with conventional concrete (CC) mixtures. For this, the lightweight aggregates were developed by calcining clay pellets in a rotary kiln at a pilot plant scale at a temperature of 1050 ° C, generating an expansion of 1.60 times of its initial size. Following the methodology ACI 211.2-98 two concrete mixtures were designed: the first, with fine and coarse aggregate of TEC; and the second, with coarse aggregate of TEC and fine aggregate of sand. It was determined that the LWC mixture with the highest efficiency is the one that uses fine and coarse aggregate of TEC, since the density of the LWC decreased by 25% with respect to the density of the CC, maintaining the resistance to compression after 28 days Under the same conditions. In conclusion, LWC mixtures made from TEC with raw materials from the metropolitan area of Cúcuta have a lower equilibrium density and compressive strength similar to that of CC.

Keywords:

Lightweight Concrete, Thermally Expanded Clay, Mechanical Behavior, Equilibrium Density, Compressive Strength, Elasticity Module, Metropolitan Area of Cúcuta.

RESUMEN

Con la finalidad de desarrollar materiales de construcción con mayor eficiencia y desempeño a la de materiales convencionales, se han generado mezclas de concreto liviano (LWC) elaborado a partir de arcilla expandida térmicamente (TEC). En el presente artículo se estudian las propiedades mecánicas (densidad de equilibrio, resistencia a la compresión) de las mezclas de LWC producidas con materia prima del área metropolitana de Cúcuta contrastando sus características con mezclas de concreto convencional (CC). Para lo anterior, se desarrollaron los agregados livianos calcinando pellets de arcilla en un horno rotatorio a escala de planta piloto a una temperatura de 1050°C, generando una expansión de 1.60 veces de su tamaño inicial. Siguiendo la metodología ACI 211.2-98 se diseñaron dos mezclas de concreto: la primera, con agregado fino y grueso de TEC; y la segunda, con agregado grueso de TEC y agregado fino de arena. Se determinó que la mezcla de LWC con mayor eficiencia es la que utiliza agregado fino y grueso de TEC, ya que la densidad del LWC disminuyó en un 25% con respecto a la densidad del CC, manteniendo la resistencia a la compresión a los 28 días en las mismas condiciones. En conclusión, las mezclas de LWC elaborados a partir de TEC con materias primas del área metropolitana de Cúcuta presentan una menor densidad de equilibrio y resistencia a la compresión similares a la de los CC.

Palabras clave:

Concreto Liviano, Arcilla Expandida Térmicamente, Comportamiento Mecánico, Densidad de equilibrio, Resistencia a la Compresión, Módulo de Elasticidad, Área Metropolitana de Cúcuta.

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Introduction

Lightweight Concrete (LWC) blends are a type of concrete in which Lightweight Aggregates (LWAC) are used, and meets the criteria established in ASTM C 330 [1], which requires a minimum compressive strength of 28 days. 17 MPa (2500 Psi) and a dry density of 1120-1920 kg/m3 (70-120 lb/ft3) [2] and consists entirely of LWAC or a combination of LWAC and normal density aggregates [3]. The Thermally Expanded Clay (TEC) aggregates are obtained by expanding the natural clay in a rotary kiln at temperatures above 1000 ° C [4].

The LWAC differ in density, strength, water absorption, surface characteristics and shape. All these differences affect the mechanical properties and durability of concrete [5]. LWAC is considered to be aggregates with a bulk density of less than 1120 kg/m3 (70 lb/ft3) for fine aggregates and less than 880 kg/m3 (55 lb/ft3) for coarse aggregates [3].

In the production of LWAC with aggregates of TEC must be pre-wet before the mixing process, otherwise, a large amount of water can be lost through the absorption during the mixing and under the pressure of the pumping concrete can lose the workability The addition of pre-moistened and porosity TEC creates optimal conditions for the hydration of cement [5].

Several studies have been carried out in the production of LWC mixtures using aggregates from TEC, as well as Chen, Yen and Lai (1995) [6], who use a limiting resistance concept for the proportion of LWC mixtures. it produces some difficulties due to the few correlations available between LWC limit strength and LWAC volume, providing the erroneous assumption that beyond the limiting strength, concrete strength varies linearly with the strength of the mortar. Chandra and Berntsson (2003) [7], proposed a technique to calculate the composition of the concrete according to the volume and strength of the mortar in the concrete and the resistance of the aggregate particles. Bogas and Gomes (2013) [8] proposed a simple mix design method for structural LWC. Although its method can be generalized to any type of LWAC, it is derived from LWC that is made with natural sand; therefore, the method is potentially limited for LWC with LWAC coarse.

To standardize the composition of the materials that make up the LWC, ACI 211.2-98 [9] recommends weight and volumetric methods to determine the proportions of the structural LWC mixture. The first is the dosage by the weight method, which is based on the amount of water contained and the relative density factor of the sizes of the individual aggregates in a moisture condition; the second, is the dosage by the volumetric method, which requires information on the bulk density, the moisture content and the proportion of coarse and fine aggregates, and the cement content.

Globally, LWAC of TEC are manufactured in more than 20 countries with several brands such as “Laterlite” in Italy, “Liapour” in Spain, “Argex” in France, “Keramzit” in Russia and “Aglite” in South Africa. In addition, they are produced in Denmark, Finland, Norway, Portugal, Germany, Italy and Iran under the brand “Leca” [4]

In Conventional Concrete (CC), the zone of normal weight aggregates is stronger than the matrix and the Interfacial Transition Zone (ITZ), in the case that lightweight aggregates are introduced into a concrete mixture, they are the weakest, which significantly affects the mechanical and elastic properties of LWC [10]. If the aggregates are weaker compared to the concrete mortar phase, the stress transfer occurs through the matrix and the cracks propagate through the lightweight aggregate particles. Therefore, lightweight aggregates are also weaker than ITZ [11], [12], [13].

In the present investigation, mechanical behavior, equilibrium density and compressive strength at 28 days will be studied for two LWC mixtures; one with thin and thick LWAC of TEC; and another one of LWAC thickness of TEC and sand as fine aggregate, produced from raw materials of the metropolitan area of Cúcuta. Comparing the results with CC mixtures.

Methodology

The proportions of the LWC and CC mixtures are presented in Table 1. For the design of the LWC mixtures, the parameters of the ACI 211.2-98 methodology [9] were followed, and for the CC mixture the parameters of the ACI 211.1-91 [14]. The mixture of CC, is composed of natural sand (0-1mm) as fine aggregate, and crushed gravel (1-10mm) as coarse aggregate, on the other hand, for the LWC mixes was used coarse aggregate of TEC (5-10mm) as coarse aggregate, for one of the mixtures (LWC-1) the

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fine aggregate is calcined clay (0-1mm) and for the other mixture (LWC-2) natural sand (0-1mm) was used.
which according to ASTM C 567 [17] is the density reached by the lightweight structural concrete after an exposure to a relative humidity of 50 ± 5% and a temperature of 23 ± 2 ° C (73.5 ± 3.5 ° F) in a period of 28 days; and the resistance to compression, determined according to the parameters of the ASTM C 39 standard [18]

The density of the test cylinders varies depending on the fine and coarse aggregates used. For LWC-1, made

Description	LWC - 1		LWC - 2		CC	
	Weight (kg/m^3)	Volume (m^3/m^3)	Weight (kg/m^3)	Volume (m^3/m^3)	Weight (kg/m^3)	Volume (m^3/m^3)
W/C	0.55		0.58		0.50	
Cement	420	0.135	400	0.129	370	0.119
Water	230	0.230	230	0.230	185	0.185
Natural sand (0-1mm)	-	-	843	0.325	791	0.305
Calcined Clay (0-1mm)	541	0.242	-	-	-	-
Crushed gravel (1-10mm)	-	-	-	-	967	0.356
TEC aggregate (5-10mm)	576	0.363	454	0.286	-	-
Air	-	0.030	-	0.030	-	0.035
Slump	8 cm		7 cm		8 cm	

Source. Authors

Table I. Design proportions of CC and LWC mixtures.

The process that was used for the production of the LWAC of TEC was as follows: natural clay from the metropolitan area of Cúcuta was crushed with the chemical characteristics necessary for the expansion, according to the criteria of Cougny (1990) [15] as shown in Table 2; the raw materials were pelleted with sizes of approximately 10 mm in diameter, clay mixtures were added with 10% of the technological nutrient to maximize the expansion capacity. The pellets were dried at 105 ° C for 25 hours, and then, according to Berg (1970) [16], who recommended carrying out a preheating heat treatment at 600 ° C for 5 min and then introducing it to the working temperature (1050 ° C).

compound	SiO_2	Al_2O_3	Fe_2O_3	SO_3	K_2O	TiO_2	MgO	CaO	Na_2O	P_2O_5	MnO
clay (% weight)	57.44	22.97	10.39	3.28	1.47	1.36	1.32	1.08	0.54	0.10	0.05
technological nutrient (% weight)	52.89	31.52	8.82	1.45	2.72	-	0.67	1.25	0.15	0.45	0.09

Source. X-Ray Fluorescence Interface Laboratory. National University of Colombia. Bogotá Colombia

Table II. X-ray fluorescence analysis of raw materials.

The thermal treatment was carried out in a rotary furnace at the pilot plant scale which has the calcination curve shown in Figure 1, a curve that generates thermal shock, due to the pellets passing from a temperature of approximately 700 ° C, to 1050 ° C in a time of 20 seconds.

The mechanical characteristics that were measured to concrete specimens are: the equilibrium density,

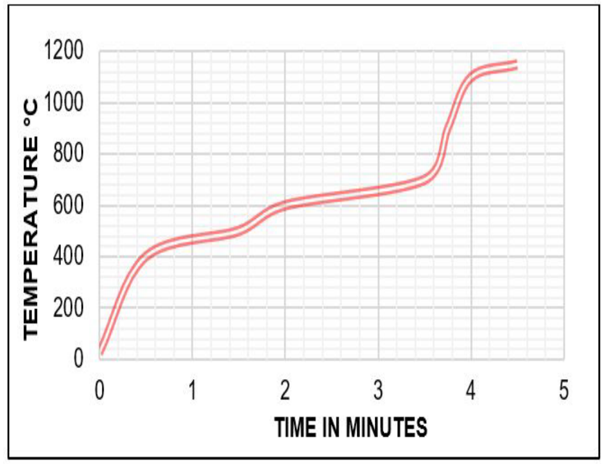

Figure 1. Calcination curve in a rotary kiln at pilot plant scale.

Source. Authors

The analysis of results was carried out with Software R (experimental design analysis program) [19]. The study was an analysis of variance, and when this presented a difference between the applied treatments, a comparison was made between them, using Fisher's Text LSD, Tukey's Text HSD and the Dukan Test.

Results

Following the processes of the ASTM C 567 [17] standard and the ASTM C 39 [18] standard, the equilibrium density and the compressive strength at the age of 28 days were determined for each of the prepared concrete specimens, the results obtained are shown in Table 3.

LWC - 1		LWC - 2		CC	
Equilibrium Density (kg/m^3)	Compressive Strengh (MPa)	Equilibrium Density (kg/m^3)	Compressive Strengh (MPa)	Equilibrium Density (kg/m^3)	Compressive Strengh (MPa)
1635.91	24.23	1865.78	25.26	2223.17	25.08
1621.70	24.22	1893.88	22.28	2242.03	27.79
1691.69	30.23	1875.39	30.97	2217.05	25.07
1642.93	29.20	1872.41	26.16	2254.36	26.39
1658.52	26.38	1835.40	32.02	2285.73	25.11
1626.20	23.72	1838.59	24.19	2212.02	29.64

Source. Authors

Table III. X- Results obtained for concrete mixtures developed.

with coarse aggregate of TEC and fine aggregate of calcined clay, densities were obtained between 1621.70 and 1691.69 kg/m3; LWC -2, development with coarse aggregate of TEC and fine aggregate of natural sand, presented densities between 1835.40 and 1893.88 kg/m3; finally, the CC made of crushed gravel and natural sand showed densities between 2217.05 and 2285.73 kg/m3 (See Table 4).

Type of mix	Equilibrium Density	std	r	LCL	UCL	Min	Max
LWC-1	1646.16	25.838	6	1623.93	1668.38	1621.70	1691.69
LWC-2	1863.58	22.623	6	1841.35	1885.80	1735.40	1893.88
CC	2239.06	27.889	6	2216.83	2261.29	2212.02	2285.73

Source. Authors

Table IV. Results of statistical analysis by Fisher's Text LSD, Tukey's Text HSD and the Dukan Test, Equilibrium Density.

The LWC-1 presented an average decrease of 26% of the density with respect to the CC and approximately 12% with respect to the LWC-2, while the LWC-2 presented a decrease in the density of 17%, on average, with regarding the density of the CC.

When evaluating the resistance to compression at 28 days of the specimens, it is observed that there are no significant differences between each of the mixtures that were developed since all specimens have an approximate strength of 26 MPa (See Table 5). It should be considered that the amount of cement varies between the mixtures as shown in Table 1, that is, to reach the strength of 26 MPa on average, different amounts of cement are needed in the mixture. The weaker the aggregate requires a greater amount of cement, since the compressive strength of the concrete is directly related to the correlation between the mortar matrix and the strength of the coarse aggregate, which is why to reach a resistance similar to that of CC, LWC-1 requires 13.5% more cement than CC; in the case of LWC-2, 8.1% more cement than CC is required, as can be seen in Table 1. Figure 2 shows that concrete failure is not only controlled by the resistance of the mortar matrix, but it is also controlled by the failure of the coarse aggregates.

Type of mix	Compressive Strength	std	r	LCL	UCL	Min	Max
CL-1	26.33	2.797	6	23.755	28.905	23.72	30.23
CL-2	26.81	3.864	6	24.239	29.388	22.28	32.02
CC	26.51	1.872	6	23.939	29.088	25.07	29.64

Source. Authors

Table V. Statistical analysis results by Fisher's Text LSD, Tukey's Text HSD and the Dukan Test, Compressive Strength.

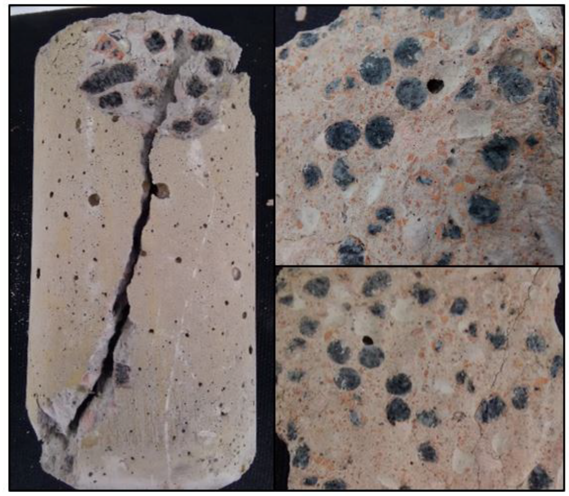

Figure 2. Test Cylinder after Compression Test.
Source. Authors

The model based on the regression coefficients is statistically significant at the 95% confidence level ($\alpha = 0.05$). For Figure 3 (a) the estimation of the developed model is (* $P = 4.4e\text{-}16 < \alpha = 0.05$), implying that the Null hypothesis is rejected, that is, there are significant differences between the density of the concrete mixtures developed. For Figure 3 (b) the estimation of the model developed is (* $P = 0.73 > \alpha = 0.05$), implying that the Null hypothesis is accepted, that is to say that there are no significant differences between the compressive strength of the mixtures of concrete developed.

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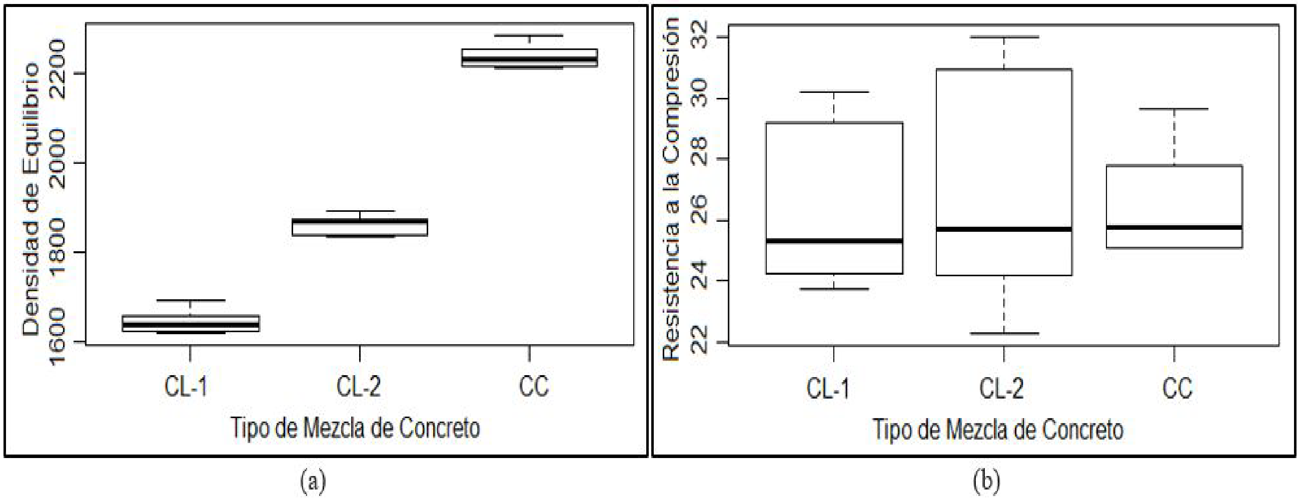

Figure 3. Box Graph (a) Equilibrium Density (b) Compressive Strength, of the concrete mixtures developed.
Source. Authors

Conclusions

After evaluating the three concrete mixtures developed (LWC-1, LWC -2 and CC), the following conclusions were reached:

• Developed structural lightweight concrete mixtures, since both the LWC -1 mixture and the LWC -2 mixture showed densities between 1120 and 1920 kg / m3 [3] (LWC -1 with 1646.16 kg/m3 and LWC -2 with 1863.58 kg/m3), in addition, the two concrete mixtures showed resistance to compression at 28 days higher than 17 MPa [3] (LWC -1 with 26.33 MPa and LWC -2 with 26.81 MPa).

• The density of the concrete is directly related to the type of aggregate that is used, since the mixture in which it used 100% of aggregates of clay (LWC -1) presented 74% of the density of the CC, while the Mixture that was developed with fine aggregate of natural sand (LWC -2) showed 83% of the density of the CC.

• The compressive strength of the concrete at the age of 28 days behaved similarly for the two (2) LWC mixtures developed, statistically, a * P = 0.73> α = 0.05 was determined, indicating that there is no difference between concrete mixtures with respect to compressive strength.

• In order for the concrete mixes to behave in the same way, with respect to the compressive strength after 28 days, it was necessary to increase the amount of cement as the content of light aggregates increased, due to the fact that the mixture LWC -1 needed 13.5% more cement than the CC mixture, however, the LWC -2 mixture only needed 8.1% more cement than the CC mixture.

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