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Concrete Blocks Using HDPE Solid Waste as Aggregate

Derling Jose Mendoza Velazco[1*], Maribel Cecilia Pérez Pirela[2], Miguel Eduardo Rodríguez Rodríguez[3], Santiago Andrés Ortiz Montero[4]

1. Technical University of Manabí (UTM), Ecuador.
2. Faculty of Engineering, National University of Chimborazo (UNACH), Ecuador.
3. Faculty of Humanistic and Technological Sciences, National University of Chimborazo (UNACH), Ecuador.
4. O & B Consulting and Architecture, Independent Researcher, Ambato, C.P. 180103, Ecuador.

*Corresponding author.
Email address: derling969@gmail.com

Abstract: The objective of this study was to analyze the addition of plastic as a partial component of the coarse aggregate in concrete, for the design of ecological blocks, establishing a linear equation that estimates the compressive strength of the block, varying the volumes of cement, sand, gravel and plastic. For the design of blocks, volume in three proportions were considered (cement/fine aggregate/coarse aggregate), thus four types of mix proportions were made (1/1/1, 1/1.25/2.5, 1/1.5/3 and 1/2/4). Coarse stone aggregate as a partial aggregate component was replaced by flake HDPE type plastic HDPE in proportions of 0, 25 and 50% coarse stone replacement. The compressive strength and unit weight of the concrete were measured after 30 days of curing. The research methodology was of a quantitative type of descriptive experimental design. The results showed that the addition of 25 and 50% plastic as a coarse aggregate reduced the unit weight of the concrete to 9.7 and 12.02% respectively. However, in this case, the reduction in compressive strength was up to 29.17 and 48.5% respectively for its best effectiveness, reducing only the unit weight of the parts.

Key words: HDPE; plastic; compression; concrete; brick; linear equation

1. Introduction

Plastic is a very common material in our daily lives. The use of plastic has increased substantially in the last decade, as it is lightweight, resistant to moisture and corrosion, durable and relatively inexpensive [1]. Plastic has replaced many traditional materials such as wood, stone, bone, leather, paper, metal, glass and ceramics. Today, almost all materials used by humans are made of plastic. As a result, plastic production has increased exponentially from 1964 to 2020 [2]. Plastic production has increased from 15 to 311 million metric tons. If this trend continues, plastic production is expected to double in 20 years and nearly quadruple by 2050 [3]. Along with production, the amount of plastic waste is also increasing exponentially. Due to insufficient recycling, millions of tons of plastic waste are generated every year, ending up in landfills and oceans. Between 22 - 43% of plastics are disposed of in landfills and at least 8 million tons of plastics are dumped into the ocean [4, 5].

In Ecuador, the first plastic industry started in 1986. Since then, plastic consumption has been increasing day by day.

In the city of Quito alone, among the total solid waste, plastic was 4.15% in 2005 and 5.46% in 2014 [6], indicating the increasing rate of plastic waste. Plastic waste can become a potential resource, if it can be recycled. One such attempt is that they can be used in concrete by solidifying this waste [7].

Several studies have been conducted to evaluate the applicability of different types of plastics for construction purposes. Jagdish et al. [8] evaluated the properties of concrete with recycled plastic as coarse aggregate at 5, 10, 15 and 20% stone replacement. They used HDPE plastic and prepared a total of 90 cylinders and 5 beams. Then, at 7, 14 and 28 days of curing, the results of compressive strength, split tensile strength, flexural strength and dry density of the specimens were analyzed. The water/cement ratio was 0.5 and the mix ratio was 1/1.8/3 by volume. According to their result, the maximum reduction in compressive strength was 44% for 20% substitution of stone by recycled plastic. The tensile and flexural strength of concrete decreased with increasing percentage of recycled plastic. Dry density decreased by 1.5% for every 5% stone substitution. At the end of their research, they pointed out that it is feasible to replace up to 15% of stone aggregate with recycled plastics for structural applications.

Subramani and Pugal [9] conducted another work on partially replacing coarse aggregates with polyhydroxybutyrate (PHB), a biodegradable plastic in which 5%, 10%, and 15% of coarse aggregates are replaced by plastic with a water/cement ratio was 0.46. It was found that 20% of the plastic waste aggregates can be replaced without long-term detrimental effects, and with acceptable strength development properties. In the experimentation of Akila et al. [11] a high applicability of plastic bags as fine aggregate in concrete was demonstrated. Plastic fine aggregate was produced by heating (178℃) the plastic bags, followed by cooling (30℃). The liquid waste was then cooled and processed in a shredding machine, which produced plastic flakes with a fineness modulus of 4.7 mm, then the 10, 20, 30 and 40% fine aggregate was replaced by plastic fine aggregate. After 28 days of curing, the workability, bulk density, ultrasonic pulse velocity test, compressive strength and flexural strength of the specimens were evaluated. Thus, the strength increased significantly with the presence of plastic bag waste. It was concluded that plastic bag can be successfully used to replace conventional fine aggregates in concrete.

According to Kamaruddin et al. [12] there are positive effects of applying plastic in concrete. For Roni et al. [13] the production costs of concrete blocks vary considerably depending on the quality, strength and utility purposes of the blocks. The standard model of dimension 40 × 20 × 20 cm has a cost of 14 US cents. For this purpose, the above-mentioned authors prepared 12 cubes of 150 × 150 × 150 mm, in which the water-cement ratio varied according to the percentage of plastic collection (0, 10, 30 and 50%). Plastic aggregates with a maximum size of 13 mm were used. The results indicate that the bulk density of the admixture decreases with the increase of plastic material, therefore the bulk density is lower than that of conventional concrete. Similarly, the reduction in bulk density was directly related to the plastic collection. The density of the material was reduced by 2.5, 6 and 13% respectively, so the reduction in density was due to the low unit weight of the plastic.

In this study, the compressive strength and unit weight of concrete were classified by considering four mix ratios (based on volume) with plastic as partial replacement (25% and 50%) of the coarse aggregate. Mix ratios that can be used for both structural and non-structural purposes were investigated according to [14 and 15]. A mathematical model was also proposed and its adequacy was evaluated using different statistical parameters. The classification of concrete blocks used in the present work is presented in Table 1 [14-15].

Table 1. Dimensions of concrete blocks

Ecuadorian Institute for Standardization Nominal Dimensions				Actual dimensions		
Type	Length (cm)	Width (cm)	Height (cm)	Length (cm)	Width (cm)	Height (cm)
A, B	40	20, 15, 10	20	39	19, 14, 09	19
C, D	40	10, 15, 20	20	39	09, 14, 19	19
E	40	10, 15, 20, 25	20	39	09, 14, 19, 24	20

2. Materials and Methods

The raw materials selected for the study were Portland cement type I ASTM C150, with 65% Chimborazo® cement containing 35% gypsum, in order to delay the setting time; fine aggregate with a fineness modulus of 2.7; coarse aggregate of 19 mm; virgin high-density thermoplastic polyethylene (HDPE) waste (without having been reprocessed), with a flow index of 77 g/10 min, water absorption mg at 96 h < 0.5; standard density of 0.963 g/cm, bending modulus of 15.396 kg/cm, tensile strength at break of 155 kg/cm, Izod impact strength of 13 kg/cm and elongation of 555%. Similarly, the HDPE had a fineness modulus of 5.91 mm, with a unit weight: 3.5 kN/m, and the water/cement ratio by weight is 0.61 (excluding air).

To mix the materials, they were selected based on the volume of cement/fine aggregate/coarse aggregate (crushed stone and recycled plastics), applying the following four sets: 1/1/1; 1/1.25/2.5; 1/1.5/3 and 1/2/4. Olonade et al. [16] replaced coarse aggregates with 0, 25, and 50% plastic aggregates when designing concrete blocks using plastic aggregates.

A clean and dry cylindrical mould with a diameter of 1000 mm and a height of 1000 mm was used to prepare the samples. Three samples were designed for each replacement. The concrete was mixed manually. The moulded material was placed in blocks of rectangular dimension 40 × 20 × 20 cm, and then left at room temperature for 24 hours. The blocks or prototypes were carefully removed from the rectangular mould. Right after removal from the mould, the materials were completely immersed in a curing tank for 30 days. Akinyele and Ajede [17] recommended a method for using UTC-0960 metal curing tanks, with an average control temperature between 38 and 40℃ with ± 2℃ accuracy. According to Shirish [18], the curing of concrete blocks with attached materials such as plastic, lime, gypsum, ashes, among others, by applying a large curing tank with dimensions of 800 × 1800 × 950 mm, can be developed with a prolonged time between 28 and 30 days, which were used during the present study.

The entire sample preparation procedure was carried out according to the American Society for Testing and Materials (ASTM) - international cement and concrete standards, where the standardized test for compressive strength of concrete block specimens corresponds to ASTM codes C39, C31, C150, C617, C1077 and C1231 [19]. After 30 days of curing, the blocks were removed from the curing tank. They were then measured by weight and tested for compressive strength. The results were compared with the standards of NTE INEN [1928].

3. Results and Discussion

This section analyses the results of the plastic addition as a partial component of the coarse aggregate in concrete for the design of green blocks. After 30 days of curing, it was observed that both compressive strength and unit weight decreased as the percentage of plastic increased for all four mix ratios (Figure 1). Based on these results, and in accordance with Shirish [18] and the NTE INEN technical standards [20-21], the intended use of the samples is included in Figure 2.

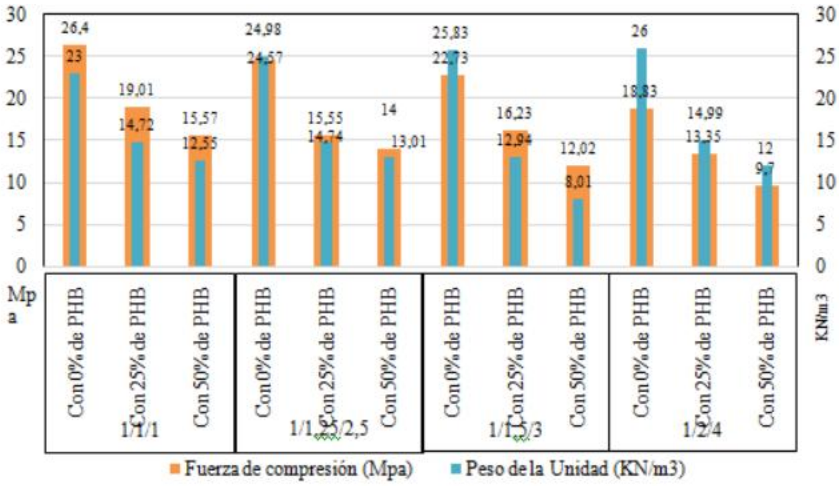

Figure 1. Compressive strength and unit weight variation with increasing percentage of plastic for each ratio.

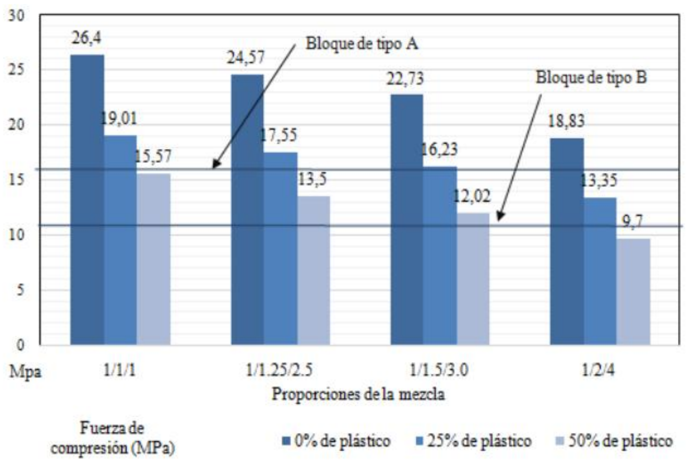

Figure 2. Results of compressive strength applied to concrete blocks.

Figure 2 shows the results of the compressive strengths obtained with the blocks made by replacing the coarse stone aggregate with 25% plastic at a ratio of 1/1/1. Similarly, the concrete samples with 25% plastic at a ratio of 1/1.25/2.5 and the concrete samples with 25% plastic at a ratio of 1/1.5/3 showed a strength of a type A block. Type A blocks, according to NTE INEN 0638 [29], are used in external load-bearing walls without facing and have a MPa ≥ 16. Except for the sample with 25% plastic in the 1/2/4 ratio, which had a MPa of 13.35, which is below the 16 MPa index.

The compressive strength results obtained by replacing 50% plastic of coarse aggregate with ratios of 1/1/1, 1/1.25/2.5, and 1/1.5/3 for concrete blocks. They have been proven to have the strength of type B block. According to NTE INEM0862 [30], type B blocks are used in exterior load-bearing walls with cladding and in interior load-bearing walls with or without cladding. The MPa range of these samples is 16 ≤ MPa ≥ 11, but the proportion of 50% plastic samples is 1/2/4, with an MPa of 9.7, which is lower than the index of 11 MPa.

3.1 Empirical development of equations

Based on the results of the previous test, the second part of the objective of this work was answered by proposing a linear polynomial regression equation in the parameters (Equation 1), using the Statistical Package for the Social Sciences (SPSS) version 25 software.

$$f'_c = -35520.66V_c-98859.50V_A-55353.74V_{pi}-71313.92V_{pl}+181.29 \quad (1)$$

In that equation, the 30-day compressive strength (f_c' in MPa) was kept as the function of the volume (in m^3) of cement (V_c), sand (V_A), stone (V_{Pi}) and plastic (V_{Pl}). The values of the input variables are shown in Table 2 (as used in the experiment).

According to Ruma and Well [31], Pearson's correlation coefficient can take values between -1 and 1. The correlation of a variable with itself is always equal to 1. For Pearson's correlation, an absolute value of 1 indicates a perfect linear relationship, while a correlation close to 0 indicates that there is no linear relationship between the variables. The value obtained for the equation was 0.97, indicating an acceptable correspondence in the linear type of covariation.

As a second efficiency criterion, the coefficient of determination was applied, according to Harel [32], which is defined as the proportion of the total variance of the variable explained by the regression. The coefficient of determination, denoted as R., reflects the goodness of a model fit to the variable that it is intended to explain. It is important to note that the value of R. sets a range between 0 and 1. The result for the proposed equation was 0.94 with a coefficient close to 1.

With the third efficiency criterion, the mean absolute error (MAE) was developed for the validation of the linear equation, with a value of 0.93. The MAE allows the measurement of the mean differences between the predicted and observed values to be determined [33].

The efficiency coefficient (E) and the modified efficiency coefficient mainly measure efficiency, but also measure the efficiency of the empirical linear equation, seeking the maximum efficiency potential by reducing or increasing plastic residues in the coarse aggregate composition, with values of 0.94 and 0.77. According to Geethu and Santhoshkumar, both oscillations with values of $1 \geq E > 5$ are considered effective [34].

Finally, among the efficiency criteria, the agreement index (D) and the modified agreement index were applied, with values of 0.99 and 0.88, representing a contribution to the linear equation, basically through the incorporation of its correction formula, which excludes agreement due exclusively to chance. This correction relates the marginal distributions in accordance with Geethu and Santhoshkumar [33]. In this sense, Equation 1 is valid within the range of applicable parameters shown in Table 4.

Table 2. Input variables volume in m^3 and compressive strength in MPa

Proportion of the mixture	Plastic content (%)	Cement (m^3) × 10^{-4}	Area (m^3) × 10^{-4}	Stone (m^3) × 10^{-4}	Plastic (m^3) × 10^{-4}	Compressive strength (MPa)	
						Data experiment	Data equation
1/1/1	0 HDPE	8.3	8.3	8.3	0	26.40	23.81
	25 HDPE	8.3	8.3	6.3	2	19.01	20.62
	50 HDPE	8.3	8.3	4.2	4.2	15.57	16.56
1/1.25/2.5	0 HDPE	5	6.7	13.3	0	24.57	23.68
	25 HDPE	5	6.7	9.7	3.4	17.55	18.25
	50 HDPE	5	6.7	6.65	6.65	13.50	13.06
1/1.5/3	0 HDPE	4.5	6.8	13.6	0	22.73	22.80
	25 HDPE	4.5	6.8	10.1	3.5	16.23	17.22
	50 HDPE	4.5	6.8	6.8	6.8	12.02	11.95
1/2/4	0 HDPE	3.6	7	14.4	0	18.83	19.59
	25 HDPE	3.6	7	10.8	3.6	13.35	13.85
	50 HDPE	3.6	7	7.2	7.2	9.70	8.10

It should be noted that all volumetric values in Table 2 correspond to a hollow concrete block sample of 40 × 20 × 20 cm. The accuracy of the linear polynomial regression equation in the parameters (Equation 1) is shown in Table 3, and it can be said that it fits well with the experimental values.

Table 3. Value of efficiency criteria

Efficiency standards	Values
Pearson's r coefficient	0.97
Coefficient of determination, R^2	0.94
Mean absolute error, MAE	0.93
Efficiency coefficient, E	0.94
Modified coefficient of efficiency	0.77
Agreement index, D	0.99
Modified agreement index	0.88

Table 4. Range of applicable parameters for Equation 1 (for a hollow concrete block sample 40 × 20 × 20 cm^3)

Parameter	Volume range in a sample (m^3) × 10^{-4}
Cement	$3.6 \leq V_C \leq 8.3$
Sand	$6.7 \leq V_A \leq 8.3$
Stone	$4.2 \leq V_{pi} \leq 14.4$
Plastic	$0 \leq V_{Pl} \leq 7.2$

The results indicate that the compressive strength of concrete blocks using plastic as a partial substitute may be significantly lower than that of ordinary concrete or control concrete. This becomes even more apparent when the percentage of plastic content as a partial substitute increases with the decrease in concrete strength. In terms of mass density of ordinary concrete and plastic concrete, as plastic concrete is made of plastic, its weight is definitely smaller compared to ordinary concrete. This indicates that plastic will be a good platform for producing lightweight concrete, producing good compressive strength.

Although researchers such as Edmund et al. [35] manage to obtain a satisfactory compressive strength, it may be that, due to the low percentage of plastic content used, as well as the types of plastics used, a significant value or coefficient is obtained, since some plastic materials are harder and stronger than others, such as polypropylene. Apart from the low percentage of plastic used, Edmund et al. [35] recommend the addition of plasticizer solution, to increase or improve the mix with plastic, as a substitute for coarse aggregate or stones. Likewise, plastic can be recommended as a substitute for fine aggregates in concrete, producing a much better result compared to the substitution of coarse aggregate.

4. Conclusion

Therefore, the recycling of plastic waste in concrete, as coarse aggregate, can be an effective solution to eliminate a large amount of plastic that can greatly reduce environmental pollution and produce a concrete environmentally categorized as green concrete.

The addition of plastic reduces the unit weight of concrete and can be used to produce lightweight concrete blocks. It replaces the strength of concrete and uses 25% and 50% of plastic as coarse aggregate, which is sufficient for high load non-structural purposes such as buildings or single or multi-story apartments.

Finally, it can be mentioned that the production costs of concrete blocks with high density polyethylene solid waste substitution have a lower economic value than conventional concrete blocks, which have a cost of 14 US cents, while these ecological blocks have a cost of 11 US cents each. The production value decreases by 3 US cents (but the process and access of the plastic appears as a partial component of the coarse aggregate, benefiting the environment by binding with the cement).

Conflicts of Interest

The author declares no conflicts of interest regarding the publication of this paper.

References

[1] Chalmin, P.: "La historia de los plásticos: desde el Capitolio hasta la Roca Tarpeya". *Field Actions Science Reports,* Vol. 19 (2019), 6-11.

[2] Chuanxiu, J., Zhang, M. y Lu, P.: "Preparación y caracterización de la urea recubierta de poliuretano/TM nano compuesto como fertilizantes de liberación controlada". *Polymer Plastics Technology and Materials,* Vol. 59, No. 9 (2020), 975-984.

[3] Moriet, A., Bleriot J., Opsomer, R., Widmer, S., Banks, I., DeSmet, M., Murphy, J., Struchery, M., Swartz, S. y Vanthournout, H.: "Foro Económico Mundial, La nueva economía de los plásticos Repensando el futuro de los plásticos". Lenaïc Gravis., Barcelona, (2016).

[4] Van Emmerik, T. y Schwarz, A.: "Los desechos plásticos en los ríos". *WIREs Water*, Vol. e1398, (2020), 1-13.

[5] Gourmelon, G.: "La producción mundial de plástico aumenta". *Recycling Lags, Vital Signs*, Vol. 11, (2015), 1-7.

[6] Veletanga, F.: "Estudio de la huella ecológica de plástico PET (Tereftalato de polietileno) del barrio Nueva Aurora en la Parroquia de Guamaní en el distrito metropolitano de Quito". Universidad Central de Ecuador., Ecuador, (2017).

[7] Awoyeraa, P. y Adesinab, A.; "Los residuos plásticos a los productos de construcción: Situación, limitaciones y perspectivas futuras". *Case Studies in Construction Materials*, Vol. 12, No. e00330, (2020), 1-11.

[8] Jagdish, K., Gohil, G y Patel, N.: "Estudio experimental sobre el uso de residuos plásticos como reemplazo parcial de los agregados gruesos y finos en el hormigón". *International Journal for Research in Applied Science & Engineering Technology (IJRASET)*, Vol. 6, No. 4 (2018), 35613567.

[9] Subramani, T. y Pugal, V.: "Estudio experimental sobre los residuos plásticos como agregado grueso para el hormigón estructural". *International Journal of Application or Innovation in Engineering & Management*, Vol. 4, No. 5 (2015), 2319-2347.

[10] Chávez-Romero, S., Aulestia-Viscarra, Sh., Cando, W., Bucheli, J. y Fernández, L.: "Evaluación de las propiedades mecánicas de una mezcla asfáltica en caliente modificada por vía seca con tapas plásticas de polipropileno". *Revista Técnica*. De la Facultad de Ingenieria, Vol. 42, No.3, (2019), 104151.

[11] Akila, S., Ajithkumar, C., Deepankumar, S., Jeeva, P. y Senthilkumari, T.: "Utilización de desechos plásticos como reemplazo parcial del agregado fino en la mezcla de hormigón". *International Journal of Advanced Science and Engineering Research,* Vol. 3, No. 1 (2018), 214-219.

[12] Kamaruddin, M., Abdullah, M., Zawawi, M y Zainol, M.: "Uso potencial de los residuos plásticos como materiales de construcción: Progresos recientes y perspectivas futuras". *IOP Conference Series: Materials Science and Engineering*, Vol. 267, No. 012011, (2017), 1-10.

[13] Roni, S., Stryjer, R., Weizman, A. y Nutt, D.: "*Spon's Architects' and Builders' Price Book 2013*". Taylor & Francis Group, Londres, (2013).

[14] Norma Ecuatoriana de la Construcción – NEC: NEC-SE-HM Estructuras de Concreto Armado. Ministerio de Desarrollo Urbano y Vivienda, (2014). https://www.habitatyvivienda.gob.ec/ wp-content/uploads/downloads/2014/08/NECSE-HM.pdf.

[15] Instituto Ecuatoriano de Normalización, INEN, Casilla 17-01-3999 – Quito-Ecuador, (1993). https://www.compraspublicas.gob.ec/ProcesoContratacion/compras/PC/bajarArchivo.cpe?Archivo=HKyt7OeS6AGvSpdetlVqXsIX2kvla To-prEqTB-tPRc.

[16] Olonade, K., Jaji, M. &Adekitan, O.: "Experimental comparison of selected pozzolanic materials". *African Journal of Science, Technology, Innovation and Development*, Vol. 9, No. 4, (2017) 381-385.

[17] Akinyele, J. &Ajede, A.: "The use of granulated plastic waste in structural concrete". *African Journal of Science, Technology, Innovation and Development*, Vol. 10, No. 2, (2018) 169-175.

[18] Deo, S.: "Mix design approach for high 28 days' strength, high-volume, low-lime fly ash concrete". *Road Materials and Pavement Design*, Vol. 16, No. 3, (2015) 707-715. DOI: 10.1080/14680629.2015.1026381

[19] Sociedad Americana para Pruebas y Materiales (ASTM): "*Annual Book of ASTM Standards*"., West Conshohocken, (2015).

[20] Servicio Ecuatoriano de Normalizacion, Norma tecnica de ecuatoriana, (NTE INEN 0157): "Cemento hidráulico. Determinación de la consistencia normal". Método de Vicat. Ecuador, (2009)

[21] Servicio Ecuatoriano de Normalizacion, Norma tecnica de ecuatoriana, (NTE INEN 0158): "Cemento hidráulico. Determinación del tiempo de fraguado". Método de Vicat, Ecuador, (2009).

[22] Servicio Ecuatoriano de Normalizacion, Norma tecnica ecuatoriana, (NTE INEN 0488): "Cemento hidráulico. Determinación de la resistencia a la compresión de morteros en cubos de 50 mm de arista". Ecuador, (2009).

[23] Servicio Ecuatoriano de Normalizacion, Norma tecnica ecuatoriana, (NTE INEN 0490): "Cementos hidráulicos compuestos". Ecuador, (2011).

[24] Servicio Ecuatoriano de Normalizacion, Norma tecnica ecuatoriana, (NTE INEN 0855): "Áridos. Determinación de impurezas orgánicas en el árido fino para concreto". Ecuador, (2010).

[25] Servicio Ecuatoriano de Normalizacion, Norma tecnica ecuatoriana, (NTE INEN 0856): "Áridos. Determinación de la densidad, densidad relativa (gravedad específica) y absorción del árido fino". Ecuador, (2010).

[26] Servicio Ecuatoriano de Normalizacion, Norma tecnica ecuatoriana, (NTE INEN 0857): "Áridos. Determinación de la densidad, densidad relativa (gravedad específica) y absorción del árido grueso. Ecuador, (2010).

[27] Servicio Ecuatoriano de Normalizacion, Norma tecnica ecuatoriana, (NTE INEN 0858): "Áridos. Determinación de la masa unitaria (peso volumétrico) y el porcentaje de vacíos". Ecuador, (2010).

[28] Servicio Ecuatoriano de Normalizacion, Norma tecnica ecuatoriana, (NTE INEN 0860): "Aridos. Determinación del valor de la degradación del árido grueso de partículas menores a 37.5 mm mediante el uso de la máquina de los Ángeles". Ecuador, (2011).

[29] Servicio Ecuatoriano de Normalización, Norma técnica ecuatoriana, (NTE INEN 0638): "Bloques huecos de hormigón, definiciones, clasificaciones y condiciones generales". Ecuador, (1993).

[30] Servicio Ecuatoriano de Normalizacion, Norma tecnica ecuatoriana, (NTE INEN 0862): "Áridos para concreto. Determinación del contenido total de humedad". Ecuador, (2011).

[31] Ruma, F. y Well, A.: "Muchas caras del coeficiente de correlación". Journal of Statistics Education, Vol. 5, No. 3 (1997), 1-13.

[32] Harel, O.: "La estimación de R2 y ajustada R2 en conjuntos de datos incompletos utilizando imputación múltiple". *Journal of Applied Statistics*, Vol. 36, No. 10 (2009), 1109-1118.

[33] Mohammad, K., Nopiah, Z.M., Ahmad Basri, N.E., Basri, H., Abushammala, M.F.M., and Maulud, K.N.A. "Previsión de residuos sólidos mediante la modelización ANFIS modificada". *Journal of the Air & Waste Management Association*, Vol. 65, No. 10 (2015), 1229-1238.

[34] Geethu, V. y Santhoshkumar, S.: "Una eficiente realización de FPGA de detección de convulsiones a partir de la señal de EEG usando la transformación de ondas y características estadísticas". *IETE Journal of Research*, Vol. 66, No. 3 (2020), 315-325.

[35] Edmund, T., Jun, C., Hejazi, F. y Jaafar, M.: "Los desechos de plástico como reemplazo parcial de los agregados - son vista". IOP Conf. *Series: Earth and Environmental Science*, Vol. 357, No. 012018 (2019), 1-7.