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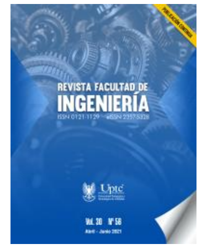

Study of the Impact of Adding Dried Biosolids to Portland-Type Cement when Making Mortars

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Abstract

This research focuses on the implementation of dried biosolids from the El Salitre wastewater treatment plant in the city of Bogotá in the mixture for the preparation of N-type mortars as a partial replacement for Portland-type cement. To carry out the experimental process, the physical properties of the materials were considered, such as their preparation and mixing, followed by the breaking test, and finally, with the collected data, the optimal percentage of biosolids for a mixture with the minimum compression strength technically required was determined. The results obtained

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show that the percentage of biosolids included in the mortar mixture is inversely proportional to the strength achieved due to the porous nature of the composition of these materials. Therefore, mixtures where 5% and 10% of the cement was replaced with dried biosolids performed better in the compression tests, even better than the conventional mixture in which these materials are not included. Consequently, these dosages can be adopted in the construction industry as an additive to the typical mortar mixture (1:4), which reduces the unfavorable environmental impact, encourages a circular economy in the industrial process of making mortars, and contributes to the sustainable development for environmental preservation. This makes the use of biosolids attractive for their inclusion as supplementary cementing material in the cement industry.

Keywords: building materials; cement; civil engineering; environmental engineering; waste treatment; wastewater.

Estudio del impacto de la adición de biosólidos secos, al cemento tipo Portland en el proceso de elaboración de morteros

Resumen

La presente investigación, se enfoca en la implementación de biosólidos secos provenientes de la planta de tratamiento de agua residual El Salitre de la ciudad de Bogotá, en la mezcla para la preparación de morteros tipo N, como reemplazo parcial del cemento tipo Portland. Para realizar el proceso experimental se consideraron las propiedades físicas de los materiales, como lo son la humedad, finura, porosidad, densidad y gravedad específica; su preparación y mezclado, para seguir con el ensayo de rotura y luego junto con los datos recolectados finalizar con la determinación del porcentaje óptimo de biosólidos para que la mezcla alcance la resistencia mecánica a la compresión mínima requerida técnicamente. Los resultados obtenidos demuestran que el porcentaje de biosólidos incluidos en la mezcla del mortero es inversamente proporcional a la resistencia alcanzada, debido a la naturaleza propia de la composición porosa de estos materiales; por lo tanto, las mezclas con sustitución del 5% y 10% del cemento por biosólidos secos presentan mejor comportamiento en los ensayos de compresión, incluso mejores resultados que los alcanzados con la mezcla convencional en la que no se incluyen estos materiales. Por ello, estas dosificaciones pueden ser adoptadas en la industria de la construcción como aditivo a la mezcla típica de morteros (1:4), disminuyendo el impacto ambiental desfavorable y los costos de producción del mortero; se incentiva una economía circular en el proceso industrial de la fabricación de morteros, y se contribuye al desarrollo sostenible para la preservación del medio ambiente. Lo que genera que el uso de los biosólidos sea atractivo para su inclusión como material cementante suplementario en la industria cementera.

Palabras clave: aguas residuales; cemento; ingeniería ambiental; ingeniería civil; materiales de construcción; tratamiento de desechos.

Estudio del impacto de la adición de biosólidos secos, al cemento tipo Portland no processo de elaboração de morteros

Resumo

A presente investigação, se enfoca na implementação de biosólidos secos provenientes da planta de tratamento de água residual El Salitre da cidade de Bogotá, na mezcla para a preparação de morteros tipo N, como reemplazo parcial del cemento tipo Portland. Para realizar o processo experimental, se considerar as propiedades físicas dos materiais, como lo son la humedad, finura, porosidad, densidade y gravedad específico; su preparação e mezclado, para seguir com o ensayo de rotação e luego junto com os dados recoletados finalizar com a determinação do porcentaje óptimo de biosólidos para que a mezcla alcance a resistência mecânica à compactação mínima necessária. Los resultados obtenidos demuestran que el porcentaje de biosólidos incluidos en la mezcla del mortero es inversamente proporcional a la resistencia alcanzada, debido a la naturaleza propia de la composición porosa de estos materiales; por lo tanto, las mezclas con sustitución del 5% y 10% del cemento for biosólidos secos presentan mejor comportamiento en los ensayos de compressão, incluso mejores results that los alcanzados con la mezcla convencional en la que no se incluyen estos materiais. Por ello, estas dosificaciones pueden retornar en la industria de la construcción como aditivo a la mezcla típica de morteros (1:4), disminuyendo el impacto ambiental desfavorable y los costos de producción del mortero; se incentiva uma economia circular no processo industrial de fabricação de morteros, y se contribui para o desarrollo sustentável para a preservação do meio ambiente. Lo que genera que el uso de los biosólidos mar atraente para sua inclusão como material cementante suplementario en la industria cementera.

Palabras clave: aguas residuales; cemento; ingeniería ambiental; ingeniería civil; materiales de construcción; tratamiento de desechos.

1. INTRODUCTION

The production of cement has been closely linked to the continuous evolution of society and, therefore, of mankind, which for centuries has used and developed different types of mixtures to produce a material suitable for construction; consequently, it has become the main input when planning engineering projects. However, due to its high demand and its large-scale production, the cement industry is responsible for around 5% of the total CO_2 emissions released into the atmosphere [1]. For this reason, cement companies around the world have sought to reduce the negative impact of producing this material by improving cement manufacturing mechanisms [2], which include the search for supplementary cementing materials (SCMs) –generally waste or by-products of industrial processes.

The wastewater treatment process generates by-products called biosolids. Biosolids are mostly used in the restoration of degraded soils; however, their production usually exceeds their management capacity [3]. As a result, wastewater treatment plants (WWTPs) are obliged to look for alternatives for the final disposal of this material. Bearing that in mind, depending on the origin of the treated water, the characteristics of the biosolids tend to change considerably and, according to their mineralogical content, it is possible to determine if they may be harmful to public health as regulated by the Ministry of Housing, City and Territory in the Decree 1287 of July the 10th, 2014 [4].

Additionally, El Salitre is the only wastewater treatment plant in the city of Bogotá at the moment. It treats the sewage of the north part of the capital, that is, about 150 tons of biosolids per day, produced by about 3 million inhabitants [3]. Initially, these biosolids were used in El Corzo, La Magdalena, and Doña Juana lands, but due to legal mechanisms and the future use of such sites, it was considered necessary to look for alternatives to the final management of the biosolids. For that reason, the immediate action plan and future alternatives for the integral management of the biosolids generated at the wastewater treatment plant in the city of Bogotá [3] suggest that the most viable and economic alternative is to incinerate them so that they can be disposed in landfills. However, the study also considered a second WWTP which is under construction and is intended to treat all the city's wastewater.

This would increase the production of biosolids to about 2,200 tons per day. Therefore, it is necessary to find more efficient and environmentally friendly alternatives such as the possibility of using them in building materials.

Furthermore, the need for the implementation of Clean Development Mechanisms (CDM) and a circular economy –in which the use of completely new raw materials is reduced to a minimum– leads to research being carried out around the world to develop ecological concrete, to the point that governmental and research entities are studying the possibility of using new materials such as household, industrial, and institutional waste in the construction industry [1].

Most biosolids contain a mineral matrix with high oxides levels such as silicon oxide (SiO_2) and aluminum oxide (Al_2O_3) which are the main constituent minerals of clay [2]. These minerals are also found in fly ash; there is extensive research on their use as a partial replacement for cementing material [5]. In some cases, they improve the mechanical properties of concrete [6]; that is why they are the most widely used supplementary cementing material (SCM) in countries such as the United States.

Considering that biosolids are similar to the minerals present in fly ash, they can be used as a material to partially replace the cement in the making of mortar mixtures. It should be highlighted that biosolids are a by-product of wastewater treatment and their generation is unavoidable; this means that the economic investment for their treatment and disposal is borne by the producing plant, representing an expense for it. Thus, the use of these materials as an input when making mortars could represent a reduction in the costs of water treatment as well as in the mortar. For that reason, their use is a promising alternative to be included not only in the cement industry but also in the wastewater treatment process.

Based on the above, this research focuses on studying the addition of dried biosolids –i.e., with humidity less than 10%, coming from El Salitre WWTP– to the cement mortar mixture by analyzing the mechanical properties of the commonly used one-to-four (1:4) ratio mixture and comparing its compression behavior with mixtures containing different proportions of dried biosolids to find the dosage that most closely resembles and meets the technical and legal specifications.

II. METHODS

A. Materials

Portland-type cement –according to the classification mentioned in Title D of the Colombian earthquake-resistant construction regulation NSR 10 (by its acronym in Spanish) [7] –, soft sand and biosolids were the materials used for the composition of the mixtures in this study. The biosolids were obtained from El Salitre WWTP in the city of Bogotá. Firstly, the sand was dried in a furnace at a temperature of 110 °C for 72 hours together with the biosolids to decrease the initial humidity (see Table 2) and achieve a value of less than 10%, which in our case was 8.3%. Subsequently, the biosolids were manually homogenized and smashed with a laboratory mortar to achieve a particle size below 75 µm that could go through the No. 200 sieve. The aim was to have a particle size similar to that of Portland-type cement [8].

The biosolids used contain minerals such as cadmium, iron, magnesium, and sodium in high concentrations [10]; therefore, they are classified as category B biosolids, as determined by the Ministry of Housing, City and Territory in the Decree 1287 of July the 10th, 2014 [4]. As a result, these types of biosolids are restricted from use in agriculture and soils where there is direct contact with people due to their high load of pollutants and heavy metals that can be harmful to public health, nonetheless, they can be used for the production of building materials.

B. Dosage for Mixtures

In the reviewed literature, authors such as Hagemann et al [1], Gastaldini et al [2]; Mozo, Gómez and Camargo [10] highlight the capacity of the dry particles in the biosolids to absorb water due to their high porosity, which is why it is not recommended to use this material in construction elements that are outdoors or continuously exposed to the weather. [5]. It is determined that the type of mortar to be mixed will be N type, taking into account the specifications mentioned in Title D of the Colombian earthquake-resistant construction regulation NSR 10 [7] whose use is limited to the general nonstructural application above ground level [11]. Thus, for every four parts of sand, one of cement is used (1:4), which varies its net content by replacing the percentages shown in Table 1 with biosolids.

A total of six types of mixtures with concentrations of 0%, 5%, 10%, 15%, 20%, and 25% of dried biosolids were prepared. They were melted into six 50 mm side cubes, resulting in a total of 36 cubes. After 24 hours of melting, they were removed from the forms and then immersed in water; 18 of them for 7 days and the rest for 14 days. Then, the specimens were tested in the ±1% compression machine and the results were analyzed [9].

Table 1. Dosage of biosolids proposed for the test.

Data dosage by m^3				
Ratio	**% Biosolids**	**Cement (kg)**	**Biosolid (kg)**	**Sand (kg)**
1:4	0	364	0	1456
1:4	0.05	345.8	18.2	1456
1:4	0.1	327.6	36.4	1456
1:4	0.15	309.4	54.6	1456
1:4	0.2	291.2	72.8	1456
1:4	0.25	273	91	1456

Note: Kilogram (Kg). Cubic meter (m^3)

C. Compressive Strength Tests

In order to determine the compression response capacity of the specimens, the standard NTC 220:2017 [12] was considered, which verified the compliance with the parameters required to obtain values close to reality, and thus, to be able to study the influence of the addition of dried biosolids to the mixture for the manufacture of the N-type mortar.

Once the aging period of the cubes in the wet room was completed, the machine was calibrated and then the compression test was performed. For this purpose, it was necessary to divide the specimens into batches according to their age and dosage. Table 3 presents the data discriminated according to these factors. From the data obtained, it was observed that the compressive strength capacity decreased as the dosage of the biosolids increased. Considering the above, and given that the strength of the cement mixtures depends, among other factors, on the age at which they fail, and which reaches the 100% resistance at the 28 days, the Spanish guideline for structural concrete was used as a reference. It provides the resistance

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percentages to be achieved at different ages [13] in order to accomplish the maximum expected strength, as shown in Figure 1.

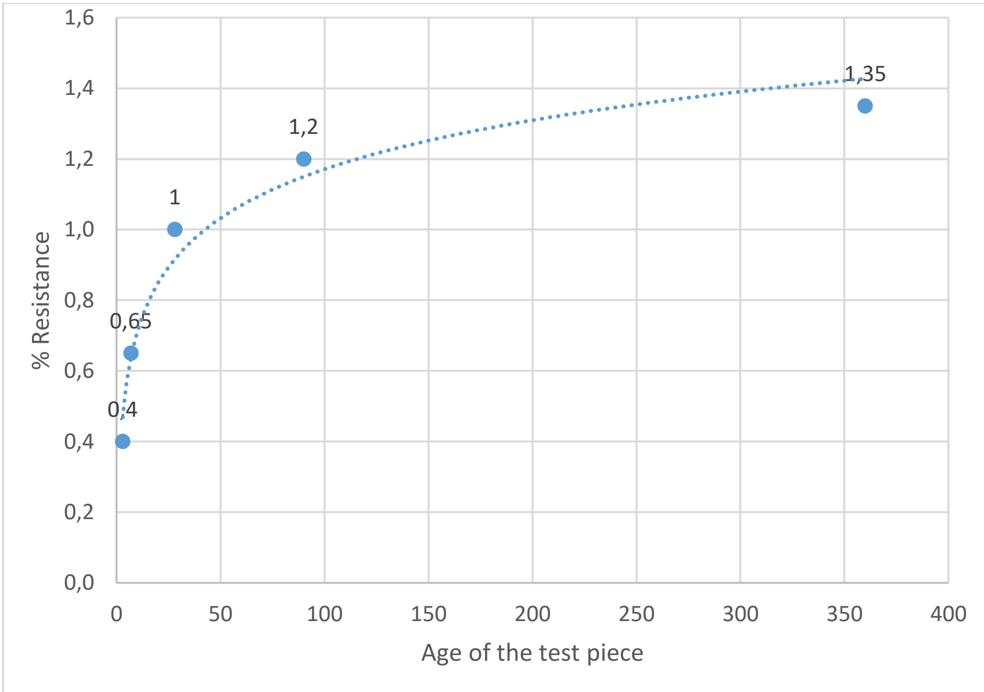

Fig. 1. Theoretically expected resistance curve at different ages.

III. RESULTS

A. Biosolids Characterization

Table 2 presents the parameters of the biosolids that determine their similarity to sands. However, by their very nature, the presence of organic matter in biosolids and heavy metals is considerably high. According to Mozo, Gómez and Camargo [10], it was found that according to measurements carried out from 2005 to 2012, the biosolids from the El Salitre WWTP have an average cadmium value corresponding to 8.12 mg*Kg^{-1}, which exceeds the permissible value of 8 mg*Kg^{-1} established in Decree 1287 of 2014. Furthermore, Rodríguez [9] points out that the biosolids coming from this WWTP have an average value of 6,038 mg*Kg^{-1} of calcium, 307 mg*Kg^{-1} of magnesium, 289 mg*Kg^{-1} of sodium, and 346.5 mg*Kg^{-1} of iron. Thus, these are the main constituent minerals of this type of materials. The results show that the specific gravity of these materials is 2.61 gr*cm^{-3}, a measurement similar to what was expected for sands (2.6 gr*cm^{-3}) [14], but considering that the objective of the study was to achieve a similar structure to that of cement, the material was smashed [8] to reach a smaller size.

In the beginning, it might be assumed that the partial replacement of biosolids is more suitable for granular material [15] than cement; however, when drying and grinding biosolids to a size below 75 μm, these are more responsive to the behavior of cement, ensuring that unwanted materials did not enter into the mixture.

Table 2. Parameters evaluated for biosolids.

Parameters	Value	Unit
Apparent density	0.72	gr/cm^3
Real density	2.62	gr/cm^3
Porosity	0.72	%
GS	2.61	-
Humidity	70.85	%

Note: Density showed in grams per cubic centimeters (gr/cm^3)

B. Determination of Material Strength

The data shown in Table 3 corresponds to the values obtained from the compression test. The best response values are consistent with the specimens with 5% of biosolids in their composition, even better results than those from the reference specimens, i.e., those of conventional mixture. Additionally, as shown in Figure 3, the trend of resistance against the percentage of biosolids that replace cement is decreasing, resulting in dosages greater than 10% of biosolids which do not meet the expected values for the failure days, suggesting that it is not possible to use it according to the Colombian earthquake-resistant construction regulation NSR 10 for N-type adhesive mortars.

Furthermore, it should be taken into account that the possible reason why the dosage corresponding to 5% of biosolids is the one with a better compression response is because of the same nature of the dried biosolids. They increase the densification of the mixture [15] so it can withstand higher compression stresses. However, since it is not possible to control the size of the particles in the biosolids

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nor their irregular distribution, when the dosage of biosolids is increased, they cause the compressive strength to decrease [2].

Although the temperature to which the biosolids are exposed does not significantly influence the strength of the material [2], the calcination does, as well as the calcination time intervals [1]. The tests of this research were carried out with dried biosolids, exposed to a temperature where it is not possible to reach calcination, so the porosity of the material increases and, therefore, its strength decreases.

Table 3. Results of the Compressive strengths tests.

Mixture code	Area (m^2)	Cubes name	Biosolids dosage	Specimen age in days	Ultimate load kN	Compressive strengths kN/cm^2	Compressive strengths MPa	Average compressive strengths kN/cm^2	Average compressive strengths MPa
A-0/7	25	A	0%	7	15.2	0.608	6.080	0.637	6.373
A-0/7	25	A	0%	7	16.8	0.672	6.720	0.637	6.373
A-0/7	25	A	0%	7	15.8	0.632	6.320	0.637	6.373
A-0/14	25	A	0%	14	19.2	0.768	7.680	0.741	7.413
A-0/14	25	A	0%	14	18.6	0.744	7.440	0.741	7.413
A-0/14	25	A	0%	14	17.8	0.712	7.120	0.741	7.413
B-0,05/7	25	B	5%	7	15.8	0.632	6.320	0.640	6.400
B-0,05/7	25	B	5%	7	15.8	0.632	6.320	0.640	6.400
B-0,05/7	25	B	5%	7	16.4	0.656	6.560	0.640	6.400
B-0,05/14	25	B	5%	14	18.8	0.752	7.520	0.763	7.627
B-0,05/14	25	B	5%	14	19.8	0.792	7.920	0.763	7.627
B-0,05/14	25	B	5%	14	18.6	0.744	7.440	0.763	7.627
C-0,1/7	25	C	10%	7	12.0	0.480	4.800	0.501	5.013
C-0,1/7	25	C	10%	7	12.8	0.512	5.120	0.501	5.013
C-0,1/7	25	C	10%	7	12.8	0.512	5.120	0.501	5.013
C-0,1/14	25	C	10%	14	14.6	0.584	5.840	0.571	5.707
C-0,1/14	25	C	10%	14	14.0	0.560	5.600	0.571	5.707
C-0,1/14	25	C	10%	14	14.2	0.568	5.680	0.571	5.707
D-0,15/7	25	D	15%	7	4.6	0.184	1.840	0.211	2.107
D-0,15/7	25	D	15%	7	5.0	0.200	2.000	0.211	2.107
D-0,15/7	25	D	15%	7	6.2	0.248	2.480	0.211	2.107
D-0,15/14	25	D	15%	14	7.2	0.288	2.880	0.312	3.120
D-0,15/14	25	D	15%	14	7.6	0.304	3.040	0.312	3.120
D-0,15/14	25	D	15%	14	8.6	0.344	3.440	0.312	3.120
E-0,2/7	25	E	20%	7	3.0	0.120	1.200	0.107	1.067
E-0,2/7	25	E	20%	7	2.6	0.104	1.040	0.107	1.067
E-0,2/7	25	E	20%	7	2.4	0.096	0.960	0.107	1.067

Mixture code	Area (m^2)	Cubes name	Biosolids dosage	Specimen age in days	Ultimate load kN	Compressive strengths kN/cm^2	Compressive strengths MPa	Average compressive strengths kN/cm^2	Average compressive strengths MPa
E-0,2/14	25	E	20%	14	5.8	0.232	2.320	0.189	1.893
E-0,2/14	25	E	20%	14	3.8	0.152	1.520	0.189	1.893
E-0,2/14	25	E	20%	14	4.6	0.184	1.840	0.189	1.893
F-0,25/7	25	F	25%	7	2.2	0.088	0.880	0.072	0.720
F-0,25/7	25	F	25%	7	1.2	0.048	0.480	0.072	0.720
F-0,25/7	25	F	25%	7	2.0	0.080	0.800	0.072	0.720
F-0,25/14	25	F	25%	14	3.0	0.120	1.200	0.125	1.253
F-0,25/14	25	F	25%	14	2.8	0.112	1.120	0.125	1.253
F-0,25/14	25	F	25%	14	3.6	0.144	1.440	0.125	1.253

Note: The results obtained per batch of dosage are indicated and discriminated according to the mixture code. Square meter (m^2). Specimen age expressed in days. Kilo Newton (KN). Kilo Newton on square centimeter (KN/cm^2). Megapascals (Mpa).

Based on the above, an interesting trend of material behavior is the 10% biosolids mixture because it meets the minimum parameters, but since it is too close to the permissible limit, it can be classified as the inflection point where the biosolids affect the structure of the mortar. In his research, Nakic [8] has determined that adding materials with high porosities generates a greater presence of air capsules contained in the mixture, which in turn increases the demand for water to achieve the final consistency. Therefore, in dosages where there is a higher concentration of biosolids, the resistance tends to decrease considerably concerning the reference mixture and what it is required by the regulations as shown in Figure 3.

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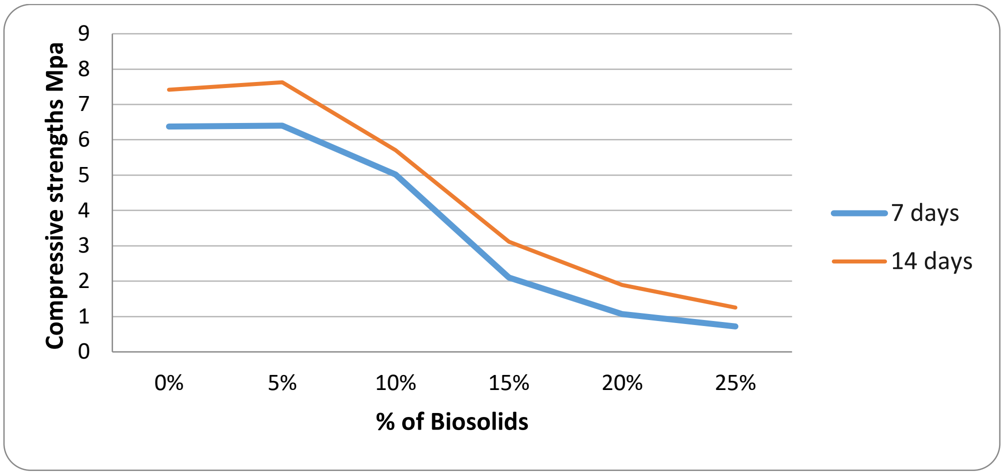

Fig. 2. Comparative graph between the resistance obtained and the specimens age (Note: Resistance expressed in Megapascal (Mpa)).

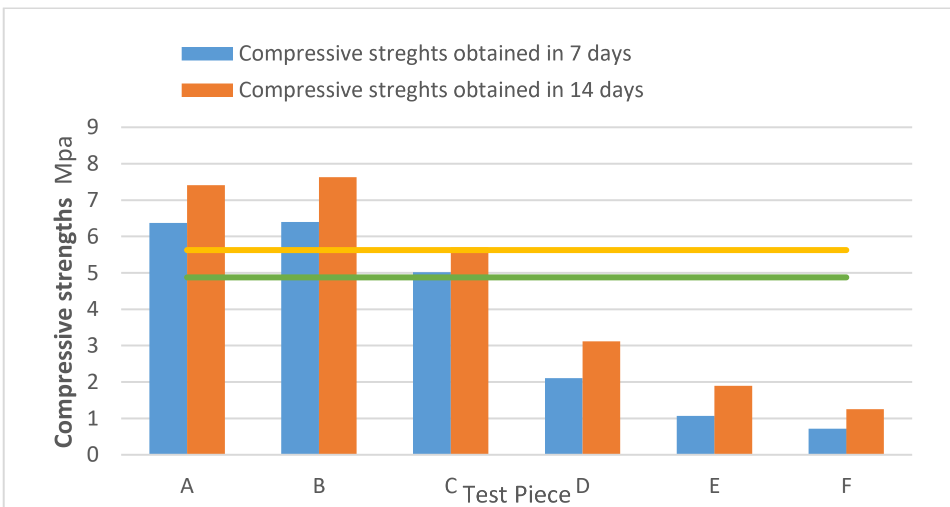

Fig. 3. Comparison of strength between test specimens (Note: Resistance expressed in Megapascals (Mpa)).

IV. Conclusions

The document shows that by exposing the biosolids to 110 ºC for 72 hours and then pulverizing them to a particle size below 75 µm, they can be used as a replacement for 5% of Portland-type cement in the mortar mixture, increasing the compressive strength capacity compared to the conventional dosage of the mixture. In addition, the study also pointed out that the maximum dosage for the resistance of the material to be admissible under the Colombian earthquake-resistant construction regulation

NSR 10 and for the mechanical properties or durability of the mortar to be not compromised is 10% of dried biosolids since, for higher figures, the decrease in resistance is significant. Therefore, the quantity of dried biosolids in addition to cement responds to a behavior inversely proportional to the required strength values. The results presented in this document suggest that the use of this material may be a viable alternative for the management and final disposal of biosolids from wastewater treatment plants, which reduces the amount of waste disposed in landfills.

Similarly, the treatment process proposed for the inclusion of biosolids as an input in the mortar mixing process is simple because it does not require the implementation of advanced technologies, the temperature range required for the drying process is not too high, and the smashing process can be done manually. Hence, the industrial cement companies can use this method without relevant issues.

AUTHOR'S CONTRIBUTIONS

Johan-Felipe Hernández-García: conceptualization, formal analysis, research, original draft writing, writing revision and editing.

Laura-Julieth Sánchez-Perdomo: research, data collection, methodology, formal analysis, original draft writing, writing revision and editing.

Gabriel-Santiago Silva-Vega: validation.

REFERENCES

[1] S. E. Hagemann, A. L. G. Gastaldini, M. Coco, S.L. Jahn, L.M. Terra, "Synergic effects of the substitution of Portland cement for water treatment plant sludge ash and ground limestone: Technical and economic evaluation," Journal of Cleaner Production, vol. 214, pp. 916-926, 2019. https://doi.org/10.1016/j.jclepro.2018.12.324

[2] A. L. Gastaldini, M.F Hengen, M. C. C Gastaldini, F.D. do Amarl, M.B. Antolini, T. Coletto, K, "The use of water treatment plant sludge ash as mineral addition," *Construction and Building Materials*, vol. 94, pp. 513-520, 2015. https://doi.org/10.1016/j.conbuildmat.2015.07.038

[3] G. S. Engineering and Construction Corporation, "*Plan de Acción Inmediato y Alternativas Futuras Para el Manejo Integral de Los Biosólidos Generados en la Planta de Tratamiento de Agua Residual de la Ciudad de Bogotá",* Empresa de Acueducto y Alcantarillado de Bogotá, Bogotá D. C., 2010.

[4] Ministerio de Vivienda, Ciudad y Territorio, *Decreto 1287 - Se establece criterios para el uso de los biosólidos generados en plantas de tratamiento de aguas residuales municipales*, 2014.

[5] C. A. García, M. C. García, M. L. Vaca, "Resistencia mecánica de ladrillos preparados con mezcla de arcillas y lodos provenientes del tratamiento de aguas residuales," *Tecnura*, vol. 17, no. 38, pp. 68-81, 2013. https://doi.org/10.14483/udistrital.jour.tecnura.2013.4.a05

[6] L. C. Prieto, A. A, Montaño, A. Parra, J. D. Puerto-Suarez, "Evaluación mecánica y ambiental del uso de cenizas volantes con activación alcalina como alternativa de reemplazo total del cemento en la elaboración de tabletas prefabricadas,*" Información Tecnológica*, vol. 30, no. 3, pp. 67-82, 2019.

[7] Ministerio de Ambiente, Vivienda y Desarrollo Territorial, *Título D, Reglamento colombiano de construcción sismo resistente NSR 10*, pp. 13-20, 1997.

[8] D. Nakic, "Environmental evaluation of concrete with sewage sludge ash base don LCA,*" Sustainable Production and Consumption,* vol. 16, pp. 193-201, 2018. https://doi.org/10.1016/j.spc.2018.08.003

[9] Y. Rodríguez, Estudio preliminar de lotes con diferente historial de incorporación de biosólidos provenientes de la PTAR el Salitre en la escombrera el Corzo, Grade Thesis, Universidad Nacional de Colombia, Bogotá D.C., 2016. https://repositorio.unal.edu.co/handle/unal/56901

[10] W. Mozo, A. Gómez, G. Camargo, "Efecto de la adición de biosólido (seco) a una pasta cerámica sobre la resistencia mecánica de ladrillos," *Revista Ingenierías*, vol. 14, no. 27, pp. 61-78, 2015. https://doi.org/10.22395/rium.v14n27a4

[11] G. López, D. Pérez, Análisis del comportamiento mecánico del mortero de pega en función de las dosificaciones por proporciones establecidas en el título D de la NSR-10, Grade Thesis, Universidad Nacional de Colombia, Bogotá D.C., 2017. http://hdl.handle.net/11349/7823

[12] INCONTEC, *NTC 220 - Cementos. Determinación de la resistencia de morteros de cemento hidráulico a la compresión, usando cubos de 50 mm o 2 pulgadas de lado*, 2017.

[13] M. Valcuende-Payá, E. Marco-Serrano, R. Jardón-Giner, A. Gil, "*Evolución de la resistencia del hormigón con la edad y temperatura",* Departamento de Construcciones y arquitectura, Universitat Politècnica de València, 2011. http://hdl.handle.net/10251/12793

[14] M. Budhu, *Soils mechanics and foundations*, New York: John Wiley & Sons, 2011 https://doi.org/10.1007/978-1-4899-7250-7

[15] C. J. Lynn, R. K. Dhir, G. S. Gathaora, R. P. West, "Sewage sludge ash characteristics and potential for use in concrete," *Construction and Building Materials*, vol. 98, pp. 767-779, 2015. https://doi.org/10.1016/j.conbuildmat.2015.08.122