Proceedings of the 7h World Congress on Civil, Structural, and Environmental Engineering (CSEE'22)
~~Lisbon, Portugal~~ Virtual Conference – April 10 – 12, 2022
Paper No. ICSECT 178
DOI: 10.11159/icsect22.178

Demolition Waste as an Alternative Aggregate for Plaster Mortars

Hernan Dario Cañola[1], Karen Venegas[2], Gersson F. B. Sandoval[3], Álisson F. do Couto[4]
[1] Grupo de Investigación Ambiente, Hábitat y Sostenibilidad,
Universitaria Colegio Mayor de Antioquia, Medellín, Colombia
hernan.canola@colmayor.edu.co
[2] Grupo de Investigación Ambiente, Hábitat y Sostenibilidad,
Universitaria Colegio Mayor de Antioquia, Medellín, Colombia
karen.venegas@colmayor.edu.com
[3] Departamento de Gestión de la Construcción,
Universidad Católica del Norte, Antafogasta, Chile
gersson.barreto@ucn.cl
[4] Departamento de Engenharias e Arquitetura,
Universidade Pitágoras Unopar Anhanguera, Arapongas-PR, Brasil
alisson.couto@kroton.com.br

***Abstract* -** The use of construction waste as an environmental alternative for this industry has become a real necessity as a consequence of the environmental degradation caused to nature. In this research, the problem of construction and demolition waste in the city of Medellín is seen as a circular economy option, since the use of this waste as an alternative to the design of plaster mortars. In this study, plaster mortar mixtures were studied with variations of 0%, 25%, 50%, 75% and 100% of waste aggregates as substitutes for natural aggregates. From the processes of characterization of the aggregate materials, the physical-mechanical tests of the mortars and the implementation of the mortars under external conditions, it was established that the use of waste aggregates allows the production of plaster mortar with similar properties to those of the conventional mortars, achieving average compressive strength of 15 MPa at 28 days for mixtures with 0% residual aggregates, 12 MPa for mixtures with 25%, 14 MPa for mixtures with 50%, 17 MPa for mixtures with 75% and 19 MPa for the mixtures with 100% of replacement; on the other hand, it was determined that the behavior against external agents regarding the presence of cracks and water penetration resistance was favorable to their relation to traditional mortars; which allowed to establish that the use of these elements as a constructive option becomes a sustainability alternative oriented to caring for the environment.

***Keywords*:** plaster mortars, prefinished,,civil constructioin waste, sustainable construction

1. Introduction

The environmental problems that have arisen as a consequence of the exploitation of natural resources have called into question the construction industry, as a consequence of the massive use of materials and exploitation of natural resources in the making of construction systems [1]–[5], however, due to the need of generating environmentally friendly alternatives, nowadays many researchers have set themselves the task of creating sustainable and resilient nature concerning alternatives with the use of construction waste implemented as primary materials in the production of construction systems and construction materials as shown below: Cañola et al [6] as an alternative to environmental care from the use of paper waste, propose a constructive option that is friendly to the environment when compared to Drywalls used today; their proposal is based on the development of modular slabs made from the mixture of paper, cement and synthetic fibers recovered from the food industry, guaranteeing compliance with physical-mechanical properties from ASTM normative parameters. On the other hand, Peña *et al.* [7] in their research on the use of demolition and construction waste, established that these materials are a great alternative as primary materials for the construction of granular bases and sub-bases implemented in roads, as an alternative to the environmental deterioration that is generated by the construction sector during the extraction of natural stone resources; in the same way, Cañola *et al.* [8], as an alternative to the protection of the environment and as a proposal for social inclusion and circular economy of rural communities, integrate education, environmental management and the collaborative work of household-head mothers in the construction of sheds, these through the use of plastic waste, demolition waste, earth, Guadua (a type of bamboo) and wood, considering this project a proposal for community food safety. Due to the foregoing, this research studies demolition and construction waste as an alternative to the primary materials used in the manufacturing of plaster mortars where caring for the environment becomes a priority for problems arising from the construction industry.

2. Methods

In this research, the physical-mechanical behavior of plaster mortars executed with waste aggregates was analyzed. 105 mortar cubes of 0.05m side were manufactured and distributed according to what is shown in Table 1, concerning test ages and percentage of waste aggregates used.

Table 1: Mix proportion and number of specimens produced

Waste aggregates (%)	Natural Aggregates (%)	w/c ratio	Number of specimens	Specimens per age (days)		
				7	14	28
0	100	0.74	21	7	7	7
25	75	0.74	21	7	7	7
50	50	0.74	21	7	7	7
75	25	0.74	21	7	7	7
100	0	0.74	21	7	7	7

For the development of this research with a quantitative-qualitative approach, the behavior of plaster mortars was analyzed with substitution of traditional fine aggregates (sand), by alternative aggregates corresponding to granular materials from demolition and construction waste. The experimental development of this research was carried out in three stages: i) characterization of waste aggregates using Ph analysis, water absorption and grain size distribution after processing (crushing and grading of demolition waste), through the normative parameter ASTM D 422 [9], ii) unit weight and compressive strength tests according to ASTM C109 [10] and elasticity modulus tests using ultrasound according to ASTM C597 –16 [11], were carried out; iii) two wall prototypes exposed to environmental conditions were built in order to evaluate their behavior against external agents and water penetration based on RILEM CPC 11.2 [12].

3. Results

The first stage of this research started with the Ph measurement of the waste and natural aggregates used in the production of the mortars; for this a WTW ™ digital pH-meter and volumetric capacity glass test tubes of 100ml were used. Once the equipment had been calibrated, a sample of 50g of natural sand and 50g of residual sand from demolition waste were taken, each of these samples was analyzed with 30ml of distilled water in the 100ml test tube, then proceeded with pH measurement using a Sentix™ 41 electrode, obtaining values of 3.61 for natural sand, characterize like an acidic pH, and 10.84 for the residual aggregate, corresponding to an alkaline pH as shown in Fig. 1; the previous analyses were made according to parameters established [13]. After this test, we proceeded in parallel with water absorption and colorimetry, from which the results are shown in Table 2, and grain size distribution. For this last analysis, a sample of 1000g of natural sand and 1000g of residual aggregates were subjected to rotary vibration processes and sieved using Ro-tap ® [9], which allowed the establishment of the percentages of retained and passing material, with which a fineness modulus corresponding to 2.28 was determined for the natural sand, characterizing the material as fine sand and fineness modulus of 2.93 for the residual aggregates, indicating that the material is a coarse sand;. It should be noted that in order to achieve an alternative mortar, the granulometry of the residual aggregates must be adapted to the particle size distribution and fineness modulus of the natural aggregates.

Fig. 1: A-B) pH analysis of the waste aggregates, C) Colorimetry analysis, D) Grain size analysis.

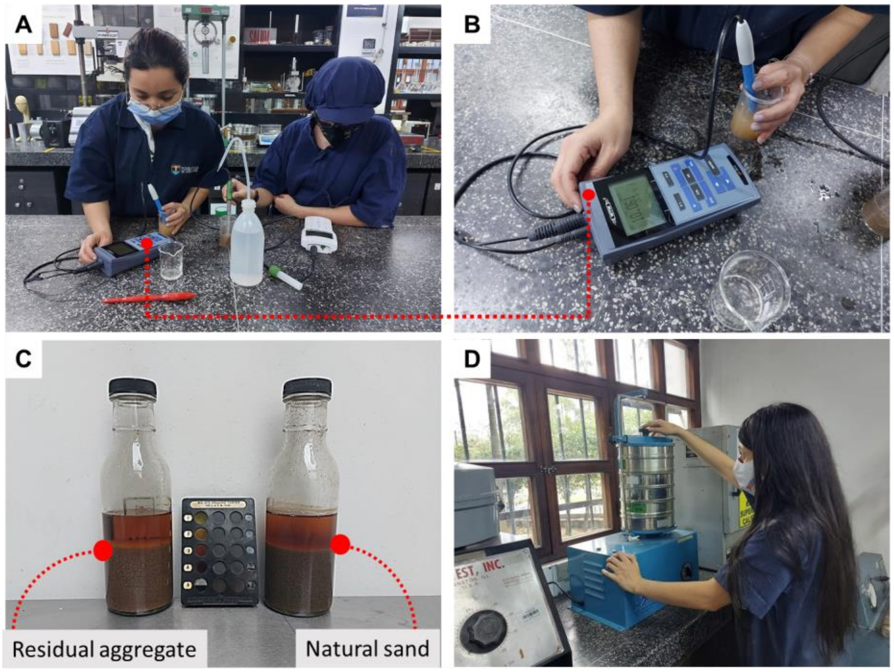


Table 2: Results of absorption and colorimetry analyses of natural and waste aggregates.

Water absorption waste aggregates (%)	Color and description according to colorimetric analysis	Water absorption natural aggregates (%)	Color and description according to colorimetric analysis
4.5	Brown	3.3	Brown

In the second stage of this investigation, the mortar mixtures were produced under the design parameters established in Table 1. Before the manufacturing of the cubes, a flow test was carried out for each of the mixtures according to ASTM C1437-01 [14], the results are shown in Table 3.

Table 3: Results of flow test for mortars with natural and waste aggregates.

Aggregates Mix		Mortar Flow		
Waste Aggregates (%)	Natural Aggregates (%)	Percentual value (%)	Consistency	Use
0	100	140	Fluid	Plaster, Grouting, self-leveling mortars for floors
25	75	150	Fluid	
50	50	139	Fluid	
75	25	146	Fluid	
100	0	143	Fluid	

Subsequently, the manufacturing of 105 cubes with dimensions of 0.05m x 0.05m was proceeded, which were then subjected to a curing process before the compressive strength analysis. For the analysis of density, absorption, and modulus of elasticity, 25 cubes were independently elaborated with variation in the percentage of residual aggregates also according to Table 1; these specimens were subjected to the curing process for 7 days, consecutively they were subjected to a drying process at a constant temperature of 100°C for 24 hours [15], at last, the correlation between masses and volumes was carried out to determine the average dry density of the samples. Once this analysis had been made, water absorption was determined using Equation 1 [16], the modulus of elasticity was determined through non-destructive tests using ultrasound, measuring the wave propagation speed through Equation 2, according to ASTM C597-16 [11]; For this test, it was guaranteed that the samples always maintained an equilibrium moisture content of 12% ± 2% in order not to generate variations. These results are shown in Table 4 and Fig. 2.

$$W_a = \frac{Wi - Wf}{Wf}\ x\ 100\% \tag{1}$$

$$E_d = \rho V^2\ \frac{(1+v)(1-2v)}{(1-v)} \tag{2}$$

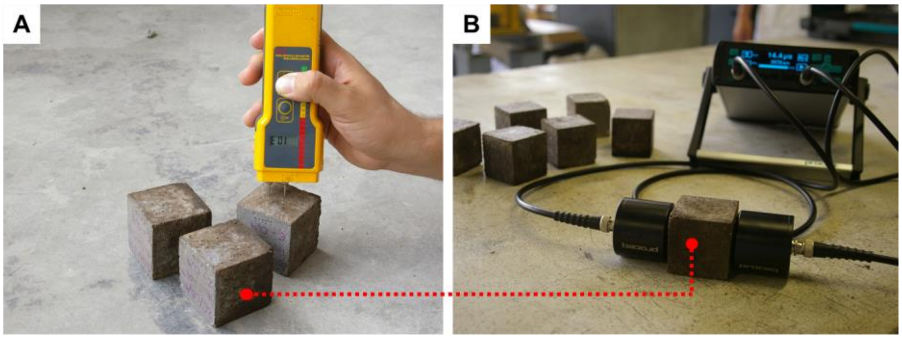
Where:

Wa: Water absorption (%)
Wi: Initial saturated sample weight (kg)
Wf: Final dry sample weight (kg)
Ed: Dynamic modulus of elasticity (GPa)
ρ : Density (kg/m3)
V : Pulse speed (km/s)
v : Poisson's dynamic modulus

Table 4: Unit weight, absorption, and elasticity modulus of the produced plaster mortars

Mix with waste aggregates (%)	Number of Specimens	Average Unit weight (kg/m^3)	Average absorption (%)	Average Elasticity modulus (GPa)
0	5	1734	17.8	16.1
25	5	1554	23.9	14.3
50	5	1538	24.7	15.6
75	5	1518	25.4	13.9
100	5	1478	25.5	12.8

Fig. 2: A) Equilibrium moisture measurement; B) Wave velocity measurement with ultrasound



After the previous analyses, the cubes were subjected to compression tests under the parameters of ASTM C109 [10] for the ages of 7, 14 and 28 days. These analyses were carried out by using a universal press, with a test duration of 5 minutes per specimen and constant speed of 0.25 MPa/s; the results of these tests are shown in Fig. 3 and Table 5.

Fig. 3: A) Mortar samples with residual and natural aggregates; B) Compressive strength test

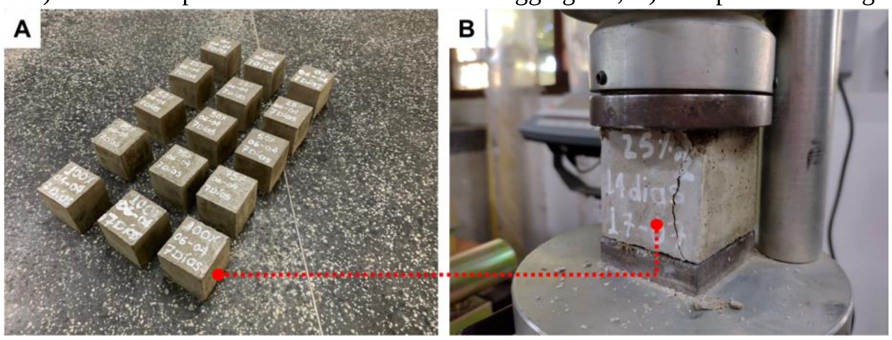


Tabla 5: Compressive strength of mortars

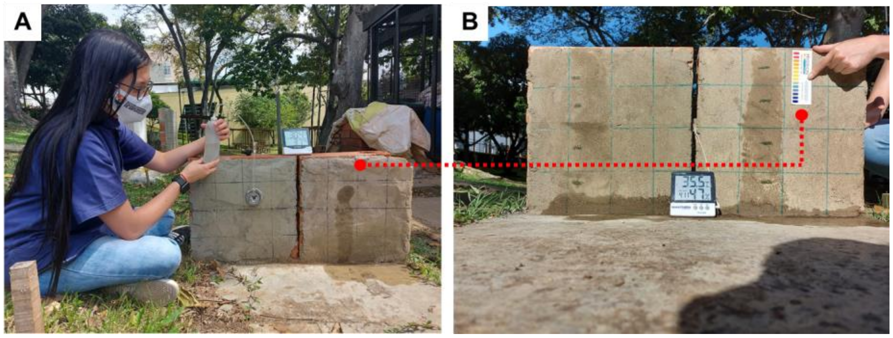
Mix with waste aggregates (%)	Compressive strength (MPa)		
	7 Days	14 Days	28 Days
0	8	14	15
25	7	12	12
50	7	13	14
75	8	15	17
100	8	18	19

The above results determine that the mortars with compressive strengths between 17MPa and 19MPa could be classified as type M and the traditional ones with a strength of 14 MPa as type S [17]. Once these analyses had been carried out, it could be seen that the mixture that guaranteed the best results when comparing the physical-mechanical properties was the one with 100% residual aggregates; then it was proceeded the elaboration of two wall prototypes with dimensions of 0.5m x 0.5m with coating in traditional and residual plaster mortar, subjected to external conditions, in which an ocular inspection was carried out, the surface pH and the resistance to water penetration were measured according to RILEM CPC 11.2 [12], 7 days after the mortar had been applied, in order to guarantee the early physical-mechanical properties of the samples. These trials were conducted weekly for 2 months; the average results of the tests are shown in Table 6 and Fig. 4.

Table 6: Surface pH measurement and resistance to water penetration results

Mix with waste aggregates (%)	Average pH	Average water penetration resistance (m^3)	
0	11	$1.3x10^{-6}$	Medium permeability
100	11	$2 x10^{-6}$	Medium permeability

Fig. 4: A) Measurement of resistance to water penetration; B) Surface pH test by marking



4. Conclusions

Aiming to potentialize the use of construction and demolition waste (CDW), as an environmental alternative to the degradation of nature generated by the construction industry, in this research it was determined that the use of this waste becomes a potential alternative to traditional plaster mortars made with natural sand. The foregoing as a consequence of the fact that its physical-mechanical properties were similar and superior in certain aspects to those of conventional plaster mortars, as indicated below:

Regarding the colorimetry test, it was established that the aggregates, both natural and waste, have brown color, according to ASTM C40/C40M [18] it is established that these materials present at most a number 3 result in the scale, which indicates they do contain enough organic matter to be harmful in mortar mixes; On the other hand, it was determined that the pH of 10.84 (alkaline) of the waste aggregates was better than that of the natural aggregates 3.61 (acidic), once the acidic pH leads to adhesion problems in the cementitious materials, which would cause them to be susceptible to durability problems related to detachments. Regarding the physical-mechanical properties, it was determined that the mortars with waste aggregates showed an increase in strength at 28 days of 27% when produced with 100% CDW, when compared to the mortars with natural aggregates. It can be concluded that the behaviour of mortars in external conditions, have similar characteristics in relation to color, whereas water penetration resistance was lower in mortars with CDW, showing an increase of 54% when compared to the traditional mortars, although both were considered as medium permeability elements [12]. It is recommended for future research to perform adhesion analysis of the plasters produced with these types of mortars and X-ray diffraction for natural and waste aggregates.

Acknowledgment

This research was developed thanks to the collaborative inter-institutional work between Colegio Mayor de Antioquia university institution and the Urban Development Company (EDU), which seeks to promote sustainability processes applied to the continuous development of the urban and rural infrastructure in the city of Medellín. For the above, the researchers of this project thank EDU for its social commitment and environmental responsibility.

References

[1] G. Babagana, A. Mohammed, and M. Garba, "Environmental impact of natural resources on terrorism in Africa," *J. Apllied techonology Environ. Sanit.*, vol. 73, no. January, pp. 95–102, 2012.

[2] G. K. C. Ding, "Sustainable construction-The role of environmental assessment tools," *J. Environ. Manage.*, vol. 86, no. 3, pp. 451–464, 2008.

[3] S. Manzi and M. C. Bignozzi, *Self-compacting concrete with recycled aggregates*. Elsevier Ltd., 2020.

[4] G. Rodríguez, C. Medina, F. J. Alegre, E. Asensio, and M. I. De Sánchez Rojas, "Assessment of Construction and Demolition Waste plant management in Spain: In pursuit of sustainability and eco-efficiency," *J. Clean. Prod.*, vol. 90, no. 2014, pp. 16–24, 2015.

[5] A. Ossa, J. L. García, and E. Botero, "Use of recycled construction and demolition waste (CDW) aggregates: A sustainable alternative for the pavement construction industry," *J. Clean. Prod.*, vol. 135, pp. 379–386, 2016.
[6] H. Cañola, C. Echavarria, and J. Sánchez, "RECIPANEL : Recycled paper panel recipanel : paneles de papel reciclado," *DYNA*, vol. 79, pp. 132–137, 2012.
[7] S. Peña, J. Terán, J. Molina, H. Cañola, A. Builes, and J. Zuluaga, "Evaluación de las propiedades de residuos de construcción y demolición de concreto para su uso en la elaboración de sub-bases granulares . Una alternativa al manejo de residuos en el Valle de Aburrá .," *Cuad. Act.*, vol. 10, pp. 79–90, 2018.
[8] H. D. Cañola, F. Granda-Ramírez, and K. L. Quintero-García, "Aprovechamiento de residuos en la construcción de galpones como alternativa de sostenibilidad en el corregimiento El Prodigio, en San Luis, Antioquia-Colombia," *TecnoLógicas*, vol. 24, no. 51, 2021.
[9] A. S. for T. and M. (ASTM), "Standard test method for particle - Size analysis of soils. D 422." West Conshohocken, 2007.
[10] Astm, "Compressive Strength of Hydraulic Cement Mortars (Using 2-in. or [50-mm] Cube Specimens). C 109." West Conshohocken, 2009.
[11] Astm, "Standard Test Method for Pulse Velocity Through Concrete." West Conshohocken, 2018.
[12] RILEM, *CPC 11.2 Absorption of water by concrete by capillarity*. 1994.
[13] J. Lee, T. Shields, and H. J. Ahn, *Performance Evaluation of Seal Coat Materials and Designs*, no. FHWA/IN/JTRP-2011/05. 2011.
[14] Astm, "Standard Test Method for Flow of Hydraulic Cement Mortar: C1437-01," *Standard*, pp. 1–2, 2015.
[15] ASTM, "ASTM C 642 – 97: Standard Test Method for Density, Absorption, and Voids in Hardened Concrete." West Conshohocken, 2016.
[16] M. Safiuddin, H. B. Mahmud, and M. Z. Jumaat, "Efficacy of ASTM Saturation Techniques for Measuring the Water Absorption of Concrete," *Arab. J. Sci. Eng.*, vol. 36, no. 5, pp. 761–768, 2011.
[17] D. Sanchez, *Tecnología del concreto y del mortero*. Bogota, 2001.
[18] A. S. for T. and M. (ASTM), "ASTM C40 Standard Test Method for Organic Impurities in Fine Aggregates for Concrete." West Conshohocken, 2014.