UNIVERSIDAD CATÓLICA SANTO TORIBIO DE MOGROVEJO
FACULTAD DE INGENIERÍA
ESCUELA DE INGENIERÍA CIVIL AMBIENTAL

A sustainable alternative for concrete construction and demolition waste (CDW-C) as an addition for subgrade stabilization

TRABAJO DE INVESTIGACIÓN PARA OPTAR EL GRADO ACADÉMICO DE BACHILLER EN INGENIERÍA CIVIL AMBIENTAL

AUTOR

Natalie Fiorella Sanchez Lopez

ASESOR

Carlos Rafael Tafur Jimenez

https://orcid.org/0000-0003-0119-8234

Chiclayo, 2022

Artículo

INFORME DE ORIGINALIDAD

23%	19%	19%	13%
INDICE DE SIMILITUD	FUENTES DE INTERNET	PUBLICACIONES	TRABAJOS DEL ESTUDIANTE

FUENTES PRIMARIAS

1	Jiawei Tan, Özlem Cizer, Jentel De Vlieger, Hancheng Dan, Jiabin Li. "Impacts of milling duration on construction and demolition waste (CDW) based precursor and resulting geopolymer: Reactivity, geopolymerization and sustainability", Resources, Conservation and Recycling, 2022 Publicación	3%
2	koreascience.or.kr Fuente de Internet	2%
3	Submitted to Universidad Nacional de Colombia Trabajo del estudiante	1%
4	Shriful Islam, Junaidul Islam, Nur Md. Robiul Hoque. "Improvement of consolidation properties of clay soil using fine-grained construction and demolition waste", Heliyon, 2022 Publicación	1%
5	nottingham-repository.worktribe.com Fuente de Internet	1%

Índice

Resumen 3

Abstract 4

Introduction 5

Methodology 6

Results 10

Conclusions 15

References 17

Resumen

Ante la necesidad de nuevos materiales que cumplan con las especificaciones requeridas para la estabilización de subrasantes, se propone el reciclaje y la reutilización de los residuos de construcción y demolición de concreto (RCD-C) con la finalidad de compensar la contaminación ambiental y al mismo tiempo preservar los recursos naturales no renovables, ante el incremento de la generación de residuos de construcción y demolición, que tienen como disposición final los botaderos y vertederos informales de las ciudades. Este estudio experimental evalúa la influencia de la adición de RCD-C en la estabilización de subrasantes de baja capacidad portante (CBR), para lograr el objetivo se adicionó 2%, 5%, 9%, 15% y 25% de RCD-C al material de la subrasante. Durante el proceso experimental se desarrollaron ensayos para determinar las propiedades físicas, mecánicas y químicas del suelo, en base a los resultados obtenidos se determinó que con el incremento de RCD-C hubo una disminución en los límites de Atterberg y un incremento en el contenido óptimo de humedad, máxima densidad seca y CBR; siendo la muestra con adición del 15% de RCD-C la que cumple con los requisitos mínimos establecidos por la normativa para un CBR correspondiente a una subrasante regular.

Palabras clave: Estabilización de subrasantes, capacidad portante, residuos de construcción y demolición de concreto (RCD-C).

Abstract

Given the need for new materials that meet the specifications required for the stabilization of subgrades, it is proposed to recycle and reuse construction and demolition waste of concrete (CDW-C) to compensate for environmental pollution and at the same time preserve natural resources. Considering that there is a continuous increase in the generation of this type of construction and demolition waste, which is deposited in landfills or informal dumps. This experimental study evaluates the influence of the addition of CDR-C in the stabilization of subgrades of low bearing capacity (CBR), to achieve the objective is added or 2%, 5%, 9%, 15% and 25% of RCD-C to the subgrade material. During the experimental process, tests were developed to determine the physical, mechanical and chemical properties of the soil, based on the results obtained it was determined that with the increase of RCD-C there was a decrease in the Atterberg limits and an increase in the optimal moisture content, maximum dry density and CBR; being the sample with addition of 15% of CDR-C that which meets the minimum requirements established by the regulations for a CBR corresponding to a regular subgrade (CBR ≥ 6).

Keywords: Subgrade stabilization, bearing capacity, construction waste and concrete demolition (CDW-C).

Introduction

In the twenty-first century, the continuous production and consumption of building materials and environmental pollution have become a global problem [1], given this, the need arises to develop new technologies or materials to reduce the environmental impact during the construction of road infrastructures. Various investigations are currently being carried out for the recycling of aggregates.

Recycling and reuse of construction and demolition waste helps offset environmental pollution while preserving non-renewable natural resources [2, 3, 4, 5]. Having various applications in road engineering, such as its use in subgrade road bases, aggregates, and soil improvement [6, 7, 8, 9, 10, 11].

Processed and selected CDW were found to be an excellent option to improve the geotechnical behavior of soils of lower strength and high compressibility for application in pavements [12, 13, 14, 15].

The main constituents of building and demolition materials are crushed bricks, construction and concrete demolition waste (CDW-C), and reclaimed asphalt pavement (RAP) [2].

Clay soils often have problems related to cracking, low strength, and high compressibility. In addition, changes in the volume of this type of soils are very sensitive to variations in moisture content. Especially in the subgrades of roads and pavements, in which various structural problems occur (cracks, potholes, grooves, irregularities) that require the replacement or maintenance of one or all layers of the road.

Considering the above, it was decided to study the land of the Urrunaga urbanization sector 1 of the district of José Leonardo Ortiz for its low resistance and its expansive potential or having consequently the absence of pavements causing negative effects such as: limited vehicular circulation and poor access to services. The management of CDW-C in the city of Chiclayo is poor, so it is common to find this type of waste on the outskirts of the city.

This research study aims to evaluate the application of CDW-C for the stabilization of clay soils, especially those with low bearing capacity (CBR). For this, three clay soils will be studied first and the most unfavorable is selected, and in that soil the values of 2%, 5%, 9%, 15% and 25% of CDW-C are added. Subsequently, the results of the sieving granulometry tests, Atterberg limits, modified proctor, California Bearing Ratio (CBR) and chemical tests such as sulfate content, chloride content and total soluble salts test are evaluated. Finally, the conclusions of the most outstanding results of the stabilization of clay soils with low bearing capacity using CDW-C are given.

Methodology

For the development of the research, a probabilistic sampling was used because the selection of sample does not depend on the probability but on the criteria stipulated in the CE.010 Urban Pavements standard. Table 1 shows the number of samples to be taken according to the type of routes to which it belongs.

Table 1. Minimum number of investigations.

Type of track	Minimum number of investigation points	Area (m^2)
Express	1 each	2000
Arterial	1 each	2400
Collector	1 each	3000
Local	1 each	3600

Source: CE.010 Urban pavements

The urbanization Urrunaga sector 1 presents unpaved streets of the local type, to determine the area is q must consider the length and width of the road. Table 2 shows the unpaved streets with their respective measurements, then the areas are added and divided by the area that corresponds to the type of road mentioned.

Table 2. Calculation of research points

Unpaved streets	Track gauge (m)	Track length (m)	Partial area (m^2)
Atahualpa	7.00	260.00	1820.00
Huascar	7.00	280.00	1960.00
Ayacucho	7.00	240.00	1680.00
Panama	10.00	250.00	2500.00
Argentina	10.00	250.00	2500.00
Santa Martha	10.00	130.00	1300.00
		Total Area	9940.00
		Total points	2.76

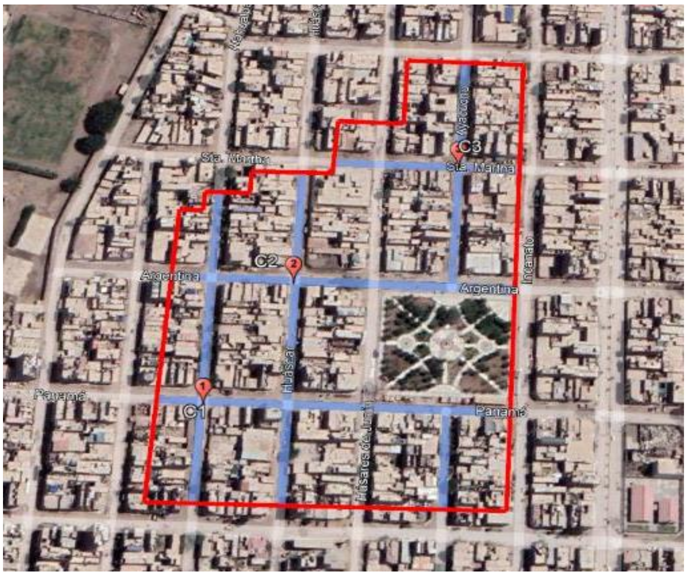
Source: Author

The nearest largest integer value of the result obtained **is** assumed, giving as 3 research points.

Obtaining the subgrade sample

To obtain the CDW-C samples, 3 manual excavations were carried out for the extraction of altered samples in the Urrunaga urbanization sector 1, district of José Leonardo Ortiz, province of Chiclayo, Lambayeque region, Peru. At the intersections of Panama and Atahualpa streets pit 01 is located, between Argentina and Huascar streets pit 02 is located and, finally, between Santa Martha and Ayacucho streets pit 03 is located, the excavation area was 0.80 m x 1.00 m approximately and with a depth of 1.50 m, Likewise, each representative sample will be approximately 180 kg for each pit and was stored in bags.

Figure 1. Location of the pits



Source: Author

Obtaining the CDW-C sample

The collection of CDW-C samples was collected from the dump located at the intersection of the Chiclayo – San José highway and the avoidance road, a representative sample of 20 kg.

Figure 2. CDW-C mounds in the dump

Source: Author

Having the CDW-C sample stored in bags, the sample was spread on a clean surface and washed to clean it of the fine particles adhered. Then the CDW-C sample was exposed to the sun for later drying, then the sample was crushed and sieved by mesh No. 80.

The sizes to be used of CDW-C in the combinations is the pass through the mesh No. 80 and 10 kg was stored.

Dosing with CDW-C

We decided to study the pit N°1 with the s dosages of 2%, 5%, 9%, 15% and 25% of CDW-C based on the international background and in the search to find the optimal percentage for the stabilization of the subgrade

Each sample with dosage of CDW-C was 28kg, for the research the pit C-01 was studied for presenting the lowest CBR value at 95% of the maximum dry density (table 4), therefore the natural humidity of that pit was used which was 21%. The dry mass being 23,140 kg and the mass of the CDW-C para 2% of 0.463 kg; for 5%, 1,157 kg; 9%, 2,083 kg; 15%, 3,471 and for 25%, 5,785 kg.

Table 3 presents the percentages and masses of CDW-C for each of the six samples to be studied.

Table 3. Dosages for CDW-C samples of pit C-1.

Sample	CDW-C content (%)	CDW-C (kg)
M-01	0	0
M-02	2	0.463
M-03	5	1.157
M-04	9	2.083
M-05	15	3.471
M-06	25	5.785

Source: Author

Tests performed

The tests carried out for the three natural samples and for the five samples with CDW-C dosage required by current Peruvian regulations are:

- Granulometry (MTC E 107)
- Moisture content (MTC E 108)
- Atterberg limits (MTC E 110, 111)
- Modified Proctor (MTC E 115)
- CBR in laboratory (MTC E 132)
- Thermal salts (MTC E 219)
- Sulphate content (NTP 339.177)
- Chloride content (NTP 339.178)

Justification for the investigation

The research will provide a new type of stabilization if it is proven that construction and demolition waste of concrete when used and applied have favorable results in the stabilization of subgrades with low bearing capacity for paving purposes. On the other hand, this research will reduce environmental and visual pollution since construction and concrete demolition waste from dumps found at the exits of the city will be used. Likewise, the problem of particulate matter generated by the circulation of vehicles and the action of the wind would be solved; it would also reduce the transmission of diseases when exposed to contact with the ground.

Results

Below, the results of the tests carried out on the natural samples in table 4 are shown, it is observed that the CBR values are less than 6% classifying the subgrade as inadequate according to the EG-2013 General technical specifications. With the results of the three pits, it was decided to study the pit C-01 because it presents the lowest percentage of CBR. The soil type of the pit C-01 is clay so of high plasticity and the pits C-02 and C-03 are silt or high plasticity, also, the results of the chemical tests show that the sample with the highest sulfate content is C-03 with 0.05% (512 ppm), the one with the highest chloride content is C-01 with 0.08% (789 ppm) and the sample with the highest content of total soluble salts is C-01 with 0.14% (1350 ppm); it is verified that each pit sample is within the range so that it does not pose a threat to the subgrade

Table 4. Results of physical, mechanical, and chemical tests of natural samples.

Test	Samples		
	C-01	**C-02**	**C-03**
Natural humidity (%)	21	23	23
Sieving granulometry			
SUCS	CH	MH	MH
AASHTO	A-7-6	A-7-5	A-7-5
Plasticity index	37	29	19
Modified Proctor			
Maximum dry density (gr/cm^3)	1.652	1.632	1.637
Optimal moisture content (%)	12.310	15.560	12.930
CBR - 0.1" (%)	1,000	1.700	1.900
Sulphate content (ppm)	426	462	512
Chloride content (ppm)	789	650	769
Total soluble s (ppm)	1350	1256	1250

Source: Author

In table 5 the results of the granulometric analysis and chemical tests of the CDW-C are shown, how the passage of mesh No. 80 was considered, being 35.90% are sands and 64.10% of silts and clays, it is classified as a type of silty soil of low plasticity according to the SUCS methodology and A-4 according to the AASHTO methodology. The results of the chemical tests carried out are within the range allowed by Peruvian regulations.

Table 5. Results of physical and chemical tests of the CDW-C sample.

Test	CDW-C sample
Sieving granulometry	
% Gravel	0
% Sand	35.90
% Silt and clays	64.10
SUCS	Ml
AASHTO	A-4
Sulphate content (ppm)	980
Chloride content (ppm)	1056
Total soluble salts (ppm)	14850

Source: Author

Table 6 shows the percentages of material corresponding to the particle size distribution (gravel, sand, and silt-clay) of the 6 samples investigated (1 natural sample and 5 samples with different percentages of addition). As can be seen the percentage of gravel varies minimally, the sample M-01 (natural) with 0.6% and the sample M-06 with 0.5%; in the percentage of the sand it can be observed that it presents a greater variation, clearly noting a tendency to increase with respect to the percentage of CDW-C, the sample M-01 with 7.8% and the sample M-06 with 30.6%; finally, with the percentage of silts and clays there is a tendency to decrease as the percentage of CDW-C increases, the M-01 sample with 91.7% and the M-06 sample with 68.9%.

The particle size variation is uniform because the addition to be used is through mesh No. 80, with a higher percentage of clays and silt (concrete particles), a good particle size distribution is necessary to ensure good compaction.

Table 6. Results of the granulometric analysis by sieving the samples with CDW-C.

Granulometric analysis				
Pit	Sample	Granulometric distribution		
		% Gravel	% Sand	% Silt and Clay
C-1	M-1	0.6	7.8	91.7
	M-2	0.6	18.3	81.1
	M-3	0.5	20.8	78.7
	M-4	0.5	23.5	76.0
	M-5	0.5	27.8	71.7
	M-6	0.5	30.6	68.9

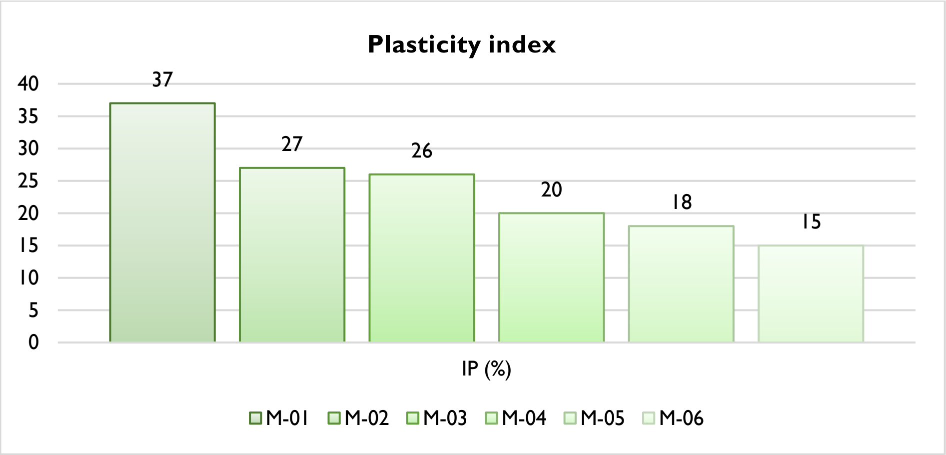
Source: Author

Figure 3 shows that the liquid limit has a tendency to decrease with respect to the percentage of CDW-C, sample M-01 with 66% and sample M-06 with 32%; in the plastic limit, in the same way, there is a tendency to decrease when increasing the percentage of CDW-C, sample M-01 with 29% and sample M-06 with 17%, the same thing happens with the plasticity index, sample M-1 with 32% and sample M-06 with 15%. The samples M-01, M-02, M-03 and M-04 belong to a high plasticity classification and the pit sample M-05 and M-06 are in the category of medium plasticity, both plasticities being characteristic of clay soils.

Figure 4 shows that as the dosage of CDW-C increases, the maximum dry density increases. As can be seen in the sample M-01 with 1,652 gr/cm^3 and the sample M-06 with 1,713 gr/cm^3. Similarly, in figure 5 it is observed that the same happens with the optimal moisture content, the M-01 sample with 12.31% and the M-06 sample with 16.10%. This indicates that the natural soil does not reach its maximum dry density because the natural moisture content is much higher than the optimal moisture content, which will result in a decrease in soil density as water occupies the voids in the soil particles.

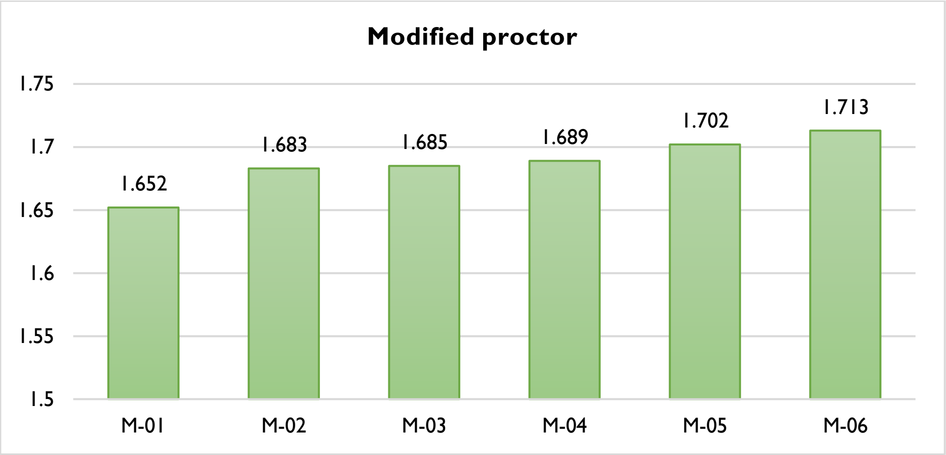
Figure 6 shows that as the dosage of CDW-C increases, the CBR increases. As can be seen in sample M-01 with 1.0% and sample M-06 with 8.1%, going from an inadequate subgrade (less than 3%) to a regular subgrade (6% out of 10%), this increase is beneficial because the thickness of the upper layers of the pavements will be reduced, saving quarry aggregates and costs.

Figure 3. Results of the plasticity index.



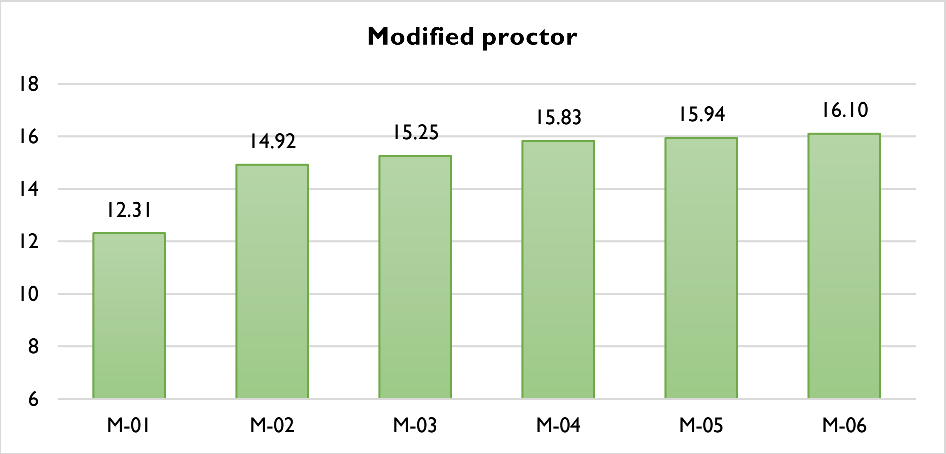
Source: Author

Figure 4. Results of the maximum dry density.



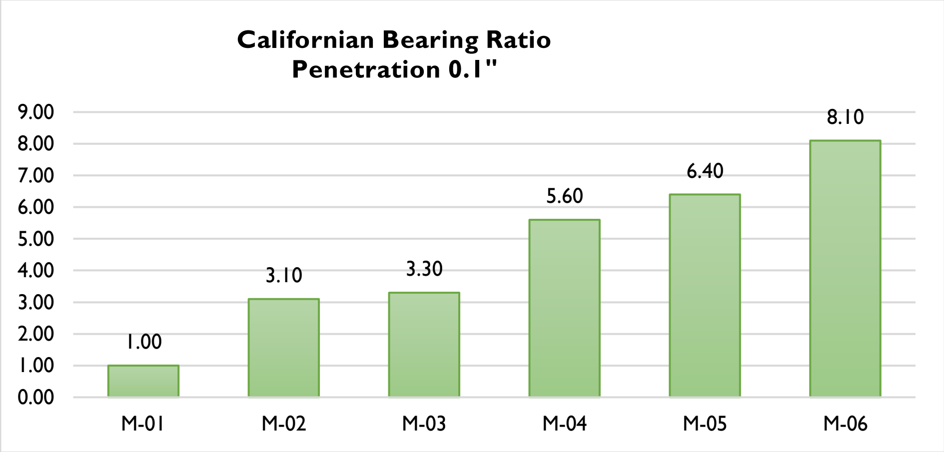
Source: Author

Figure 5. Results of optimal moisture content in percentage



Source: Author

Figure 6. CBR results.



Source: Author

Table 5 shows the results of the physical, mechanical, and chemical tests performed on the six CDW-C dosed samples. The results of the chemical tests carried out are within the range allowed by Peruvian regulations, which indicates that the addition of CDW-C does not harm the subgrade.

Table 5. Results of physical, mechanical, and chemical tests of samples with CDW-C dosing.

Test	Sample					
	M-01	M-02	M-03	M-04	M-05	M-06
Sieving granulometry						
SUCS	Ch	Cl	Cl	Cl	Cl	Cl
AASHTO	A-7-6	A-7-6	A-7-6	A-7-6	A-6	A-6
Plasticity index	37	27	26	20	18	15
Modified Proctor						
DMS (gr/cm3)	1.65	1.68	1.69	1.69	1.7	1.71
OCH (%)	12.3	14.9	15.3	15.8	15.9	16.2
CBR - 0.1" 95% MDD (%)	1.0	3.1	3.3	5.6	6.4	8.1
Sulphate content (ppm)	426	524	542	526	645	526
Chloride content (ppm)	789	759	685	812	956	819
Total soluble salts (ppm)	1350	1450	1345	1412	1495	1452

Source: Author

Conclusions

Based on the results obtained in the laboratory tests for the standard sample and the additions of 2%, 5%, 9%, 15% and 25%, the following was concluded:

- The characterization of CDW-C by sieve granulometric analysis was considered as a sample of the percentage that passes the No. 80 sieve, resulting in 35.9% sand and 64.1% silt and clay.
- It is concluded that the M-01 of the pit C-01 according to the SUCS methodology is a "CH" clay of high plasticity and for the AASTHO methodology belongs to group A-7-6 with a group index greater than 10. For all samples with the addition of CDW-C the classification of the soil according to the SUCS methodology is "CL" clay of low plasticity with sand and for the AASTHO methodology for samples M-02, M-03 and M-04 is maintained in group A-7-6 with a group index greater than 10, for sample M-05 changes A-6 with group index greater than 10 and for M-06 is A-6 with a lower group index of 9.
- The modified Proctor test showed that the maximum dry density and optimum moisture content increases as the addition of CDW-C increases. The standard sample obtained 1,652 gr/cm 3 of maximum dry density and 12.31% optimal moisture content, with the sample M-05 1,702 gr/cm 3 and 15.94%, and with the sample M-06 1,713 gr/cm^3 and 16.10%. Likewise, it is observed that the soil does not reach its maximum dry density because the natural moisture content is greater than the optimal moisture content of each of the samples.
- In the CBR test it was observed that the bearing capacity increases as the percentage of addition of CDW-C increases. The standard sample obtained 1% of CBR to 95% of the MDD being a value not suitable for subgrades, with the addition of 15% of CDW-C the CBR was increased to 6.40% representing an increase of 540% and with the addition of 25% of CDW-C the CBR was increased to 8.10% representing an increase of 710%. The M-01 subgrade sample of the pit C-01 went from the category of inadequate subgrade to regular subgrade from the M-05 sample with 15% addition of CDW-C.
- It is concluded that the optimal percentage of CDW-C to stabilize the subgrade is the addition of 15% CDW-C (sample M-05) because a CBR of 6.40 to 95% MDD is

achieved with a penetration of 0.1", complying with the regulatory requirements for the subgrade (CBR≥6). It is necessary to emphasize that with the addition of 25% of CDW-C (sample M-06) the value of the CBR continues to increase, however, as the M-05 sample already complies with the regulations it is the selected addition.

- It is concluded that samples M-05 (15% addition of CDW-C) and M-06 (25% addition of CDW-C) are those with the CBR value greater than or equal to 6 complying with the minimum requirements established by current national regulations.
- Subgrade stabilization with the addition of RCD-C significantly reduces environmental impacts, being beneficial to the environment because it is reusing construction and demolition waste of concrete as a material that solves a problem present in the study area, as well as creates employment opportunities and serves as a new alternative for stabilization or improvement of subgrade to continue studying within the field of engineering.

Finally, we conclude that the addiction of CDW-C allows to stabilize subgrades of low bearing capacity.

Acknowledgements

Thank my advisor Lucas Ludeña Gutierrez and my colleague Cesar Anthony Nima Puse for their collaboration during the development of the research in the experimental phase.

References

[1] K. Marzieh, T.S. Piltan, M.B. Seyed, M. Alireza, A. Arul, "Utilization of recycled concrete aggregates for light-stabilization of clay soils", *Construction and Building Materials*, pp.227, December 2019. https://doi.org/10.1016/j.conbuildmat.2019.116792.

[2] R. Cardoso, R.V. Silva, J. De Brito, R. Dhir, "Use of recycled aggregates from construction and demolition waste in geotechnical applications: a literature review", *Waste Manage*, vol. 49, pp. 131-145, March 2016. https://doi.org/10.1016/j.wasman.2015.12.021.

[3] M.A. Rahman, M.A. Imteaz, A. Arulrajah, M.M. Disfani, S. Horpibulsuk, "Engineering and environmental assessment of recycled construction and demolition materials used with geotextile for permeable pavements", *J. Environ. Eng.*, vol. 141, pp. 9, September 2015. https://doi.org/10.1061/(ASCE)EE.1943-7870.0000941

[4] J. Tavira, J.R. Jiménez, J. Ayuso, M.J. Sierra, E.F. Ledesma, "Functional and structural parameters of a paved road section constructed with mixed recycled aggregates from non-selected construction and demolition waste with excavation soil", *Constr. Build. Mater.*, vol. 164, pp. 57-69, March 2018. https://doi.org/10.1016/j.conbuildmat.2017.12.195.

[5] C. Sangiorgi, C. Lantieri, G. Dondi, "Construction and demolition waste recycling: an application for road construction", *Int. J. Pavement Eng.*, vol. 16, pp. 530-537, 2015. https://doi.org/10.1080/10298436.2014.943134.

[6] J. Tavira, J.R. Jiménez, E.F. Ledesma, A. López-Uceda, J. Ayuso, "Real-scale study of a heavy traffic road built with in situ recycled demolition waste", *J. Clean. Prod.*, pp. 248. March 2020. https://doi.org/10.1016/j.jclepro.2019.119219.

[7] J. Zhang, L. Ding, F. Li, J. Peng, "Recycled aggregates from construction and demolition wastes as alternative filling materials for highway subgrades in China", *J. Clean. Prod.*, pp. 255, May 2020. https://doi.org/10.1016/j.jclepro.2020.120223.

[8] N.K. Bui, T. Satomi, H. Takahashi, "Enhancement of recycled aggregate concrete properties by a new treatment method", *Geomate J*, vol. 14, pp. 68-76, January 2018. https://geomatejournal.com/geomate/article/view/624.

[9] C.P. Ginga, J.M.C. Ongpeng, M.K.M. Daly, "Circular economy on construction and demolition waste: a literature review on material recovery and production", *Materials (Basel)*, vol. 13, pp. 1-18, June 2020. https://doi.org/10.3390/ma13132970.

[10] S. Lotfi, M. Eggimann, E. Wagner, R. Mróz, J. Deja, “Performance of recycled aggregate concrete based on a new concrete recycling technology”, *Constr. Build. Mater.*, vol. 95, pp. 243-256, October 2015. https://doi.org/10.1016/j.conbuildmat.2015.07.021.

[11] A.K. Suluguru, S.R. Surana, A. Guharay, A. Kar, J. Muktinutalapati, “Experimental investigations on building derived materials in chemically aggressive environment as a partial replacement of soil in geotechnical applications”, *Geotech. Geol. Eng.*, vol. 37, pp. 947-963, August 2019. https://doi.org/10.1007/s10706-018-0662-0

[12] S. Pourkhorshidi, C. Sangiorgi, D. Torreggiani, P. Tassinari, “Using recycled aggregates from construction and demolition waste in unbound layers of pavements”, *Sustain Times*, vol. 12, pp. 1-19, November 2020. https://doi.org/10.3390/su12229386.

[13] J. Zhang, F. Gu, Y. Zhang, “Use of building-related construction and demolition wastes in highway embankment: laboratory and field evaluations”, *J. Clean. Prod.*, vol. 230, pp. 1051-1060, September 2019. https://doi.org/10.1016/j.jclepro.2019.05.182.

[14] V. Kerni, V.K. Sonthwal, U. Jan, “Review on stabilization of clayey soil using fines obtained from demolished concrete structures”, *Int. J. Innov. Res. Sci. Eng. Technol.*, vol. 4, pp. 296-299, May 2015. http://www.ijirset.com/upload/2015/may/106_Review.pdf

[15] M. Jayatheja, A. Guharay, A. Kar, A.K. Suluguru, "Building derived materials—sand mixture as a backfill material”, *Sustain. Environ. Infrastructure, Lect. Notes Civ. Eng.*, 90, 437-446, September 2021. https://doi.org/10.1007/978-3-030-51354-2_40.