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Circular Economy: GreenConcrete Bioproduct is used to produce construction materials from tailings.

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ABSTRACT: In recent years, there has been a shift in companies from a linear to a circular economy for various reasons, including environmental care, raw material dependency, and reducing the emission of polluting gases, among others. In the case of large mining companies, the sustainability and viability of their production depend on the recycling of tailings, which are produced in large quantities annually. Lately, attempts have been made to use tailings as a construction material; however, only partial replacement of tailings in concrete manufacturing has been achieved, ranging from 5 to 20% of the final product. In this paper, we show the results of using biocementation, which has allowed us to create a construction material using over 95% tailings as the primary raw material. The biocementation has managed to change the physical characteristics of the tailings without generating greenhouse gases. The results were increasing its compression strength by 25% compared to untreated tailings. Additionally, it possesses acoustic and thermal insulation characteristics, similar to approved construction products. Finally, we have succeeded in producing moldable products using 3D printing. We are in the final phase of achieving a finished construction product based on 100% tailings.

KEYWORDS: tailings, circular economy, biotechnology, construction.

1 INTRODUCTION.

Biomineralization is a process by which living organisms can produce minerals for protection or reinforcement. This process spans from microorganisms to higher organisms, and examples can be found in nature such as bones, corals, and shells, among others (Wu et al., 2021). In microorganisms, mineral synthesis is divided into biologically controlled mineralization (BCM) and biologically induced mineralization (BIM). In the latter, mineral production is extracellular and has been used for engineering applications (Dhami et al., 2013). Numerous microorganisms have been used for BIM, the most common being calcite precipitation through urea hydrolysis by ureolytic bacteria (Wu, 2021). In this specific case, the process is called Microbially Induced Calcite Precipitation (MICP). This process has been applied in civil engineering, including soil consolidation, bioremediation of heavy metal pollution, restoration of degraded stone surfaces, self-healing concrete, and carbon dioxide sequestration (Hoffmann, 2021).

The potential application of MICP in construction has garnered significant attention in recent years. This is because the construction sector, responsible for a staggering 39% of global carbon dioxide (CO2) emissions, is projected to increase its share to 57% in the coming decades with the surge in construction activities. This underscores the urgent need to explore and adopt less polluting alternatives for this industry (Beatty, 2022).

On the other hand, globally, Chile is one of the world's largest mining industries. Due to its production processes, it generates critical liabilities such as tailings due to the large annual volumes produced. It is estimated that 600 million tons are produced annually, with a projected increase to 1 billion tons for the next decade (Cochilco, 2022). Tailings are mainly composed of silicon oxides, iron, aluminum, and calcium, which can account for up to 90% of their composition. They are a fine material, with 80% measuring below 100 micrometers. Due to these characteristics, they are a strong candidate to replace cement in construction materials. This study presents the results obtained by using MICP to convert tailings into construction material.

1.1 *Physical-chemical analysis of copper tailings*

The first activity involved the analysis of the size and composition of two copper tailings samples: one comprising complete tailings and the other corresponding to the fine or slurry part obtained after cyclone separation. Table 1 shows the percentage of fine material composing the 2 samples. As expected, the slurry sample consists of approximately 81% particles with a size smaller than 0.075mm, compared to the complete tailings which have 62% of particles below that size.

Table 1. Comparison of the percentage of fine particle size (under 0.075 mm) between tailings and slurry.

Material	*< 0,075 mm*
Tailing	62%
Slurry	81%

Table 2 shows the mineralogical composition of the two samples, analyzed using Polycrystalline X-ray Diffraction, using Equipment: Bruker D8 Advance Diffractometer. Over 90% is composed of silicon, aluminum, iron, and calcium crystals.

Table 2. Mineralogical comparison of the tailings and slurry samples.

Crystalline phase	*Tailings* %	*Slurry* %
Albite	52,9	49,9
Quartz	28,2	28,4
Orthoclase	-	13,7
Sanidine	13,4	

Muscovite	1,7	3,1
Clinochlore	2,4	2,9
Gypsum	1,4	2,0

This composition is similar to what is found in cement, which includes silicon dioxide, calcium oxides, aluminum, and iron. Therefore, it is an excellent candidate for exploring its potential as a construction material.

1.1. *Biocementation of tailings and slurry*

To assess the bio-cementation capacity of the tailings through the MICP process, a mixture of the solid sample with the biotechnological product GreenConcrete was prepared. This product consists of bacteria with cementing capacity. The biocementation capacity was evaluated using the Unconfined Compression Test according to the NCh 3134 standard (NCh3134:2007). The tests were conducted by constructing specimens compacted to a dry density of ρd = 1.56 g/cm3 with an optimum compaction moisture of 20%. Subsequently, they were dried under ambient conditions, and once the residual moisture was reached, their strength was tested. The 20% moisture content corresponds to water as a control (tailing water and slurry water) or to the GreenConcrete product (Tailing GreenConcrete and slurry GreenConcrete).

The tests were conducted in duplicate, and the average was graphed. In Figure 1, the obtained strength was evaluated using GreenConcrete in the two samples studied. As observed, the control samples treated with water exhibit lower strength than those treated with GreenConcrete. Furthermore, a significant difference in strength is observed with the sample containing a higher percentage of fine material (slurry), with GreenConcrete increasing the strength by 45% compared to the water-treated sample.

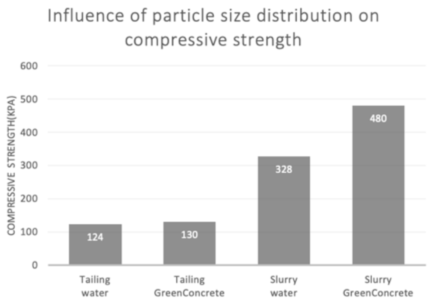

Figure 1. Influence of particle size distribution on compressive strength attainment through bio-cementation.

These results demonstrate the importance of particle size distribution in the strength obtained by the bio-cemented material. As a result, the subsequent tests were conducted using the fine tailings or slurry.

1.2. *Use of additives to improve the strength of slurry.*

To increase the strength of the biocement produced with slurry, the test was conducted by adding rubber powder as an additive, another mining waste. This additive come from 100% recycled rubber from end-of-life OTR tires with a diameter of 0.2 mm, this additive was generously donated by the Chilean company Isolcork.

The strength tests were performed by adding 5 or 30% rubber to the mixture. The strength results are shown in Figure 2A. Additionally, the stiffness results were plotted in Figure 2B.

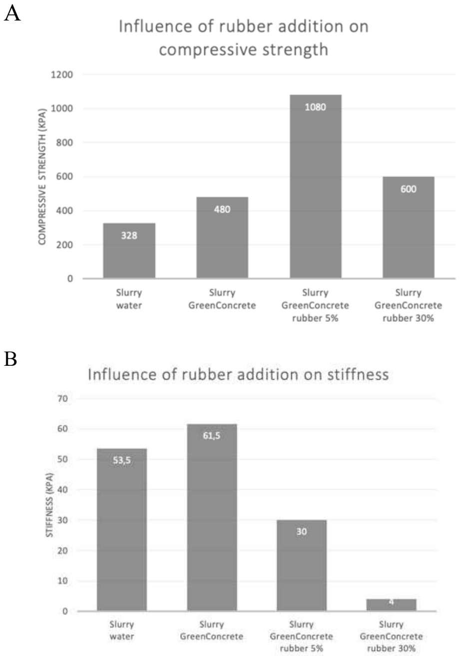

Figure 2. A. Influence of rubber addition on compressive strength attainment through bio-cementation. B. Influence of rubber addition on stiffness through bio-cementation.

The results showed that rubber at 5% can deliver greater strength, doubling the original value, however, with 30% rubber, stiffness decreases, but ductility increases. These results are promising as they indicate that it is possible to obtain construction materials with different characteristics depending on the proportion of additives used.

1.3. Evaluation of insulating characteristics of the developed product GreenConcrete

Acoustic and thermal insulation tests were conducted to determine if the obtained construction product could be used as insulation.

1.3.1 Acoustic insulation

This test involved acoustic modeling. Overall indices in dB(A) were calculated using the Insul acoustic calculation software, version 9.0.11., based on the following data provided: GreenConcrete (5% rubber): thickness: 5 cm, density 1560 Kg/m3, Young's Modulus 188,71 MPa and Shear modulus 54.20 MPa. GreenConcrete (30% rubber): thickness: 5 cm, density 1207 Kg/m3, Young's Modulus 52.70 MPa and Shear modulus 18.01 MPa.

This modeling was performed for GreenConcrete with 5% and 30% rubber and compared with products with certified construction materials (Table 3).

Table 3. Comparison of Sound Reduction Index dBA of different materials

Material	*Index dBA*
GreenConcrete 15 mm (5% rubber)	*37*
GreenConcrete 15 mm (30% rubber)	35
Fibrocement 15 mm	36
Cement sándwich panels	35-42

Table 3 shows that the biocemented slurry with different rubber concentrations achieves Sound Reduction Index values similar to those of certified construction materials as acoustic insulators.

1.3.2 Thermal insulation

The thermal conductivity coefficient was determined according to the standard NCh850.Of. 2008 “Thermal insulation - Determination of steady-state thermal resistance and related properties - Guarded hot plate apparatus.” In this case, the product with 5% rubber was used. The thermal conductivity result was 0.263 W/mK.

To obtain the thermal transmittance, it was verified according to the Chilean Standard NCh No. 853/2007 and required in article 4.1.10 of the General Ordinance of Urban Planning and Construction (OGUC).

The evaluated construction elements were as follows:

Wall 1: A partition wall with a thickness of e = 80 [mm] and GreenConcrete panels 10 [mm] thick.
Wall 2: Partition wall with thickness e = 90 [mm] with GreenConcrete panels 15 [mm] thick.
Wall 3: GreenConcrete wall 5 [mm] thick.

In Table 4, the results of thermal transmittance for each of the evaluated construction elements are shown.

Table 4. Comparison of thermal transmittance of the evaluated construction elements.

Material	*U: [W/M2K]*
Wall 1	*0,79*
Wall 2	0,76
Wall 3	2,78

Table 5 shows compliance by thermal zones according to Article 4.1.10 of the General Ordinance of Urbanism and Construction. The thermal transmittance [U] of the evaluated wall construction solutions must equal or be less than the corresponding value for each thermal zone.

Table 5. Compliance with thermal zones

Thermal Zone OGUC	*Reference Zone*	*Max.U wall*	*Wall 1 U: 0,79*	*Wall 2 U: 0,76*	*Wall 3 U: 2,78*
1	I to III	*4,00*	*C*	*C*	*C*
2	IV to V	3,00	C	C	C
3	RM	1,90	C	C	NC
4	VII to VIII	1,70	C	C	NC
5	IX to XIV	1,60	C	C	NC
6	X	1,10	C	C	NC
7	XI to XII	0,60	NC	NC	NC

C:	Complies
NC:	No Complies

1.3. *3D printing using GreenConcrete*

Using 3D printing, the first moldable products have been generated using GreenConcrete technology. Currently, these products have been achieved with the addition of 20% clay as an additive, and the effect of heat treatment has been evaluated, consisting of 15 minutes of heating using a microwave. Figure 3 shows the products obtained without heat treatment A and with heat treatment B.

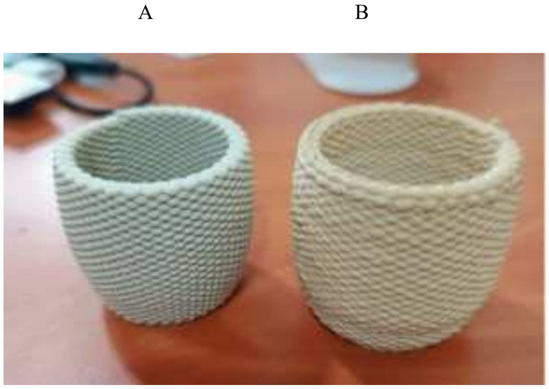

Figura 3. 3D printing of GreenConcrete using 20% clay. A. Without heat treatment. B. With heat treatment.

2 CONCLUSIONS

In recent years, efforts have been made to add value to the tailings generated yearly by large-scale mining operations in significant quantities (Vargas 2020; Lam 2020; Gou 2019; Sigvardsen 2018). However, adding them in small proportions to concrete has only been possible. Therefore, the most significant result of the present study is that by using MICP, it is possible to achieve a product composed mainly of tailings (over 95%) with a compression strength above 1 MPa. This achievement opens the door to seeking new additives that increase the required strength for construction-capable cement.

Additionally, it was determined that finer particle size distribution yields better strength results. With the inclusion of additives such as 5% rubber, compression strength was increased by up to 140%.

The results of the sound reduction index and thermal transmittance indicate that the product can be used as both acoustic and thermal insulation, opening the possibility of generating a wide variety of products with this aim.

3 ACKNOWLEDGMENTS

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