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Analysis of the current scenario of Compressed Earth Block (CEB) production

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ABSTRACT

The main objective of this study is to identify the parameters that influence the quality of the production of compressed earth blocks (CEB). Thus, an analysis of the performance of the materials that make up the final product was carried out, such as the binders that act as chemical stabilizers and the different types of soils, also the mechanical resistance and durability tests and finally the technical standards for its manufacturing. For this aim, a literature review was carried out in three electronic databases, Scopus, Web of Science and Scielo. The results showed environmental concerns with the use of Portland cement for stabilization, therefore, 18% of the studies used agricultural residues and 25% used mineral by-products, for partial or total replacement of Portland cement. Soils with plasticity indexes between 15% and 30% have a stabilization success rate of 69%, while soils with plasticity index less than 15% have a stabilization greater than 93%, which can be increased to 100% if the soil have a percentage of clay and silt between 21 and 35%. On the other hand, a plasticity index above 30% negatively affects stabilization. The compaction energy applied in the manufacture of CEB is an important parameter, as it influences the density, thermal conductivity and mechanical strength. Among the sustainable construction techniques, CEB is a great option, as it can be done locally and with ease of construction.

PALAVRAS-CHAVE: Soil cement. CEB. Ecologic brick.

1 INTRODUCTION

Shelter is one of the basic needs of human beings, and the lack of resources and the increasing cost of materials have motivated engineers and architects to find new alternatives to conventional building materials (steel, concrete and burnt brick) such as CEB, which is manufactured by mixing moist soil compacted in a press operated manually or mechanically, hydraulically or manually, to obtain a high-density block.

The performance of CEB is managed by the requirements of construction standards, where soil characteristics, especially grain size distribution, are of great importance, according to Kasinikota; Tripura (2021) each soil fraction has a significant impact on mechanical behavior and a small variation in particle size can change soil structure, plasticity, cohesion and permeability. There are some factors that contribute to the effectiveness of the blocks, such as: soil granulometry, mixing water content, compaction energy and type and quantity of stabilizers. However, if the technological control is not well executed, the blocks can have disadvantages of compressive strength limitations, loss of saturation resistance, lower durability, shrinkage cracking and low dimensional stability, which also limits the number of floors used in buildings (Danso, 2017; Elahi et al, 2020).

Another important factor for good performance is the use of cement as a chemical stabilizer, as it contributes to the strength and durability properties required for blocks, on average, 10% cement by weight of the soil mixture (Hany et al 2021) However, cement manufacturing produces significant amounts of greenhouse gases, which have created many environmental problems over the years. Therefore, research seeks other sources of stabilizers that are sustainable and ecological, such as industrial waste and by-products (Rivera et al, 2021).

The main advantages of CEB, compared to conventional materials, as a building material are: reduced carbon oxide emissions, high thermal and acoustic insulation, lower energy consumption, reduced transport costs, in addition to easy accessibility, along with improvement of the local economy (Elahi et al 2021; Sekhar and Nayak, 2018; Seco et al, 2017).

Therefore, this research distinguishes the main findings of recent literature for the production of compressed earth blocks.

2 OBJECTIVE

This research carried out a survey of scientific documents on the main parameters that influence the quality of compressed earth block (CEB) production, such as binders, soil types, technical standards for production and performance analysis, in the period 2017 to 2021, in three databases Scopus, Web of Science and SCIELO.

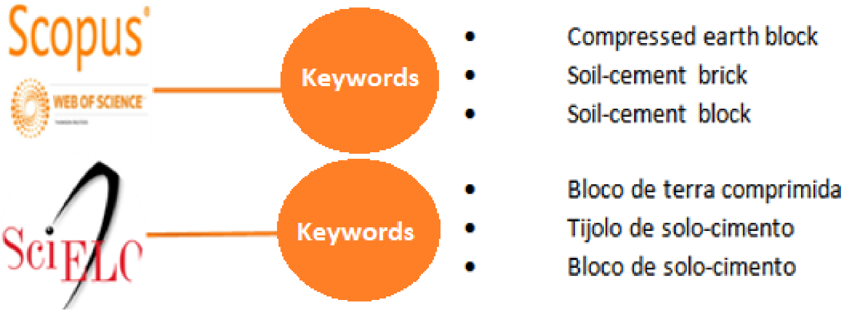
3 METHODOLOGY

3.1 Databases and Keywords

In order to carry out the search for documents that portrayed the objective of the research, the terms and definitions disclosed on Soil-cement blocks in the Brazilian standard ABNT NBR 10834:2012 were investigated, which establishes the requirements for the receipt of Soil-cement blocks, intended for to the execution of masonry without a structural function. With this preliminary information, sets of keywords were created to search for scientific articles in the electronic databases: Scopus, Web of Science and Scielo.

The following keywords were used in the Scopus and Web of Science databases: Compressed earth block, Soil-cement brick and Soil-cement block. For Scielo, as this is a Brazilian database, the keywords in Portuguese were used: Compressed earth block, Soil-cement brick and Soil-cement block (Figure 1).

Figure 1: Databases and Keywords



Source: Database website, edited by the authors, 2021.

3.2 Filters

The results of the number of researches found were delimited by filters (Figure 2), presented from F1 to F7:

F1 - Selected fields: article title, abstract and keywords.

F2 - Works published from 2017 to 2021.

F3 - Articles only: exclusion of conference papers, book chapters and systematic literature reviews.

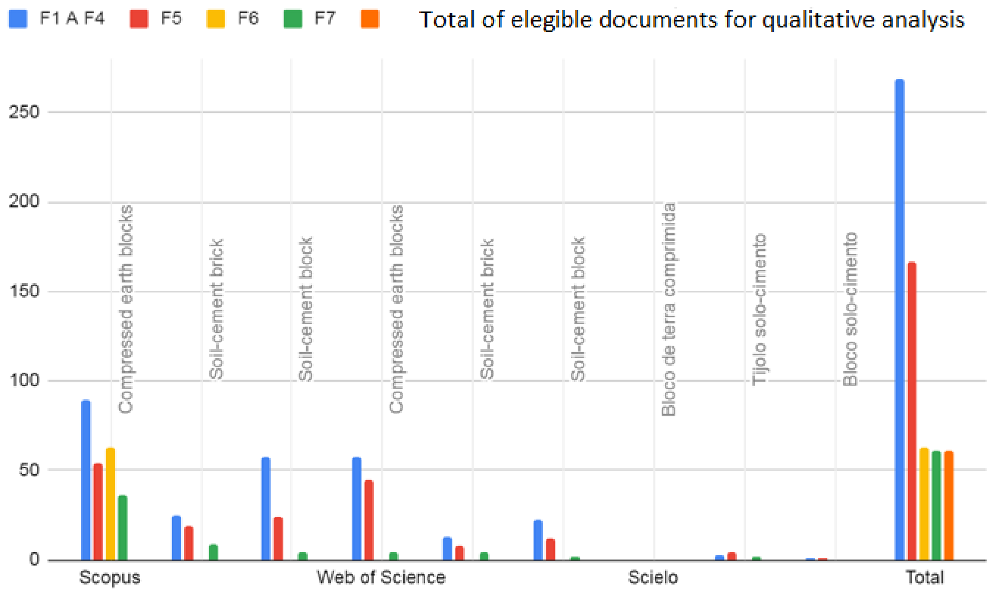
F4 - Articles restricted to the areas of architecture, engineering, social sciences, arts and humanities.

F5 - Journals classified as A1, A2, B1 and B2 by the Brazilian quality assessment system, QUALIS/CAPES, quadrennium 2013-2016.

F6 – Subtraction of documents due to duplication between bases.

F7 – Subtraction of documents due to lack of adherence to the research objective.

Figure 2: Identification and filters of researches



Source: THE AUTHORS, 2021.

For content analysis of the present research, 61 articles were inserted. The results and discussions will be presented in 4 sections:

- Analysis of the bibliographic production of the clipping
- Materials
- CEB production methods
- Performance evaluation

4 RESULTS E DISCUSSIONS

4.1 Analysis of the bibliographic production of the clipping

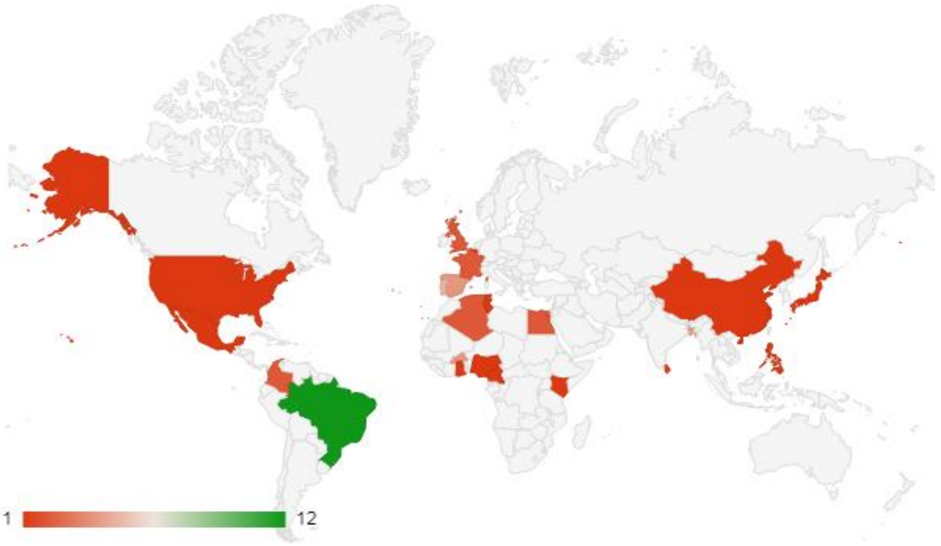
Among the 61 articles, the year 2020 stands out in publications, in which the number of works more than doubled compared to 2019 (Table 1). The interest in developing technology with stabilized earth material is increasing, this due to concerns with production processes of masonry materials, mainly with productions with high consumption of incorporated energy, and carbon dioxide emissions. There is an interest from all over the world in researching about CEB, from developing countries such as Brazil, China and India, and developed nations such as Spain, Portugal, England, France and the USA (Figure 2).

Table 1: Number of documents versus year

Year	2021	2020	2019	2018	2017
N of documents	11	17	8	13	12

Source: THE AUTHORS, 2021.

Figure 2: Production by country



Source: THE AUTHORS, 2021.

From the 61 documents, 31 belong to the Construction and Building Materials journal, corresponding to 50.8% of the total sample. The most cited authors in the period were Sekhar; Nayak (2018) with 36 citations in Scopus and 27 in Web of Science. The universities that stand out in this section are: Bangladesh University of Engineering Technology and Institut International d'Ingénierie de l'Eau et de l'Environnement from Burkina Faso, with 6 and 5 articles published respectively.

4.2 Materials

4.2.1 Stabilizers

For the production of CEB, Portland cement is normally used as a stabilizer, on average 10% by mass. With environmental concerns, especially with climate change, research seeks to use products and/or by-products with a low environmental footprint for partial or total replacement of Portland cement. In this research, it was no different, 18% of the investigations used agricultural residues, such as rice husk ash, object of six studies, and sugarcane bagasse ash, from three studies. Another fifteen studies used mineral by-products: granulated blast furnace slag, metakaolin, silica fume, calcium carbonate residue, the highlight being fly ash with nine analyses.

4.2.1.1 Mineral Stabilizers

Hany et al (2021) investigated the production of two CEB mixtures with proportions of 90% soil + 10% cement and prepared with different compaction pressures of 9 N/mm^2 and 16 N/mm^2, with a result of compressive strength of 6.99 and 8.58 N/mm2 respectively. Another six mixtures were prepared using fly ash, silica fume, metakaolin, rice husk ash and granulated blast furnace slag, as partial or total replacement of cement. The use of alkali activated fly ash and granulated blast furnace slag as a cement replacement in proportions of 80% and 100%, respectively, was superior in the stabilization of CEB with competitive compressive strength compared to cement-stabilized ones. However, cement stabilization in BTC exhibits smaller voids and greater water resistance, resulting in better durability compared to other stabilizers. The replacement of 0.25% soil with rice husk plus addition of 10% cement has a significant effect in increasing the compressive strength and water resistance of the produced CEBs due to their reinforcing effect.

Elahi et al (2020) evaluated the strength and durability performance. The CEBs were prepared with 4%, 6%, 8% and 10% cement and 0%, 10%, 20%, 30% fly ash. For 4% and 6% of cement, the ideal content of fly ash was 10%. For 8% cement, 20% fly ash, and for 10% cement the ideal content of fly ash was 30%. The resistance to wet compression, with 6% of cement and addition of 10% of fly ash is adequate to provide a wet-to-dry strength ratio greater than 0.33, meeting the recommendations of Minguela (2017). The 8% cement content with 10% fly ash meets the criteria, whereas with 10% cement any amount of fly ash is sufficient to make the blocks durable. In another article by Elahi et al (2021) on investigating the performance of BTC stabilized with cement and fly ash, it was concluded that for compressive strength the content of 20% fly ash with 5% or 7% cement satisfies the criterion suggested by different standards. Islam et al (2020) found the ideal blend composition in terms of strength, durability, deformation characteristics and cost effectiveness. The inclusion of 7% or 8% cement and 15% to 20% fly ash provides dry compressive strength greater than 5 MPa, wet-dry compressive strength greater than 0.33, and sufficient durability in terms of lower water absorption than 20% as recommended by BS 3921:1985 and Standards Australia: 2002.

Sekhar; Nayak (2018) studied the use of granulated blast furnace slag and cement in the manufacture of CEB. Both CEB s prepared with 75% lithomagic clay soil + 25% granulated blast furnace slag + 10% cement, and those prepared with 80% lateritic soil + 20% slag + 6% cement can be used for the construction of load-bearing walls. Seco et al (2017) in their experiments analyzed various combinations of soil+sand and different stabilizers, such as Portland cement, hydraulic lime, PC-8[1], CL-90-S[2], and granulated blast furnace slag. The best results in terms of mechanical resistance and durability were obtained with the mixture of PC-8 + granulated blast furnace slag, with values between 11.1 and 13.7 MPa.

Akinyemi; Orogbad; Okoro (2021) investigated the physical, mechanical, thermal and microstructural properties of clay bricks from termite mounds stabilized with calcium carbide residues. Four different mixing ratios were carried out: 0%, 10%, 20%, and 30% cement combined with replacement of 0%, 10%, 20% and 30% calcium carbide residue, all with addition of chemical additive of 0.1 g. The study showed that the incorporation of 10% calcium carbonate, 20% cement and a chemical additive 0.1g in termite clay soil reached 3.0 MPa wet compression strength, lower shrinkage and lower water absorption. of 15% after 24 h, in conclusion this dosage would help in the development of CEB.

Nshimiyimana et al (2021) evaluated the durability of CEBs with 0% to 25% by mass of calcium carbide residue (RCC) and soil. Durability indicators reached optimal values with 10% to 15% calcium carbide residue. The capillary absorption coefficient was below the recommended limit of 20 g/cm².min1/2, with 15% of calcium carbide residue, the minimum values of 9.9 g/cm² were reached. min1/2. The abrasion coefficient of the stabilized CEBs was higher than the 7

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[1] PC-8 is a Mg-rich by-product obtained during the production of calcined magnesite by calcining natural MgCO3 rocks to 1100 °C.

[2] CL-90-S: hydrated limestone, obtained from pure burned limestone.

g/cm² required for use in façade masonry and reached 16 g/cm² with 15% calcium carbide residue. Stabilization with RCC from 10% to 25% increased the abrasion resistance and the compressive strength of the CEBs after the drying and wetting cycles. The authors pointed out that stabilization with at least 10% calcium carbide residue is beneficial for the long-term durability of BTCs. However, water absorption increased from 18% to 24% and exceeded the limits of 15% to 20% recommended for use in a humid environment. In 2020, the same authors published an article evaluating the compressive strength of CEB stabilized with 0 to 20% by weight of calcium carbide residue, and concluded that the best stabilizer content was 20% in any soil in the study.

Chabeddra; Kharchi (2019) studied the impact of sulfates on the behavior of CEBs stabilized with different formulations of cement and lime-based binders. The blocks were submitted to a reference chemical cure, involving sulphates and water. Sulphates are very harmful in the case of thin soil with lime incorporation, whereas thick soil stabilized with cement is better resistant to sulphate attack. Heifer; Azeredo (2019) evaluated the influence of capillary absorption time and sulphate ion concentration in CEBs stabilized with 12% of cement, exposed to sulphate attack. The capillary absorption time influenced the wear of the samples, in general, longer exposure intervals caused greater damage. Fragmentation and cracking occurred in samples tested with capillary absorption times of 1 week and 2 weeks, using a 10% sodium sulfate concentration.

Santos et al (2020) studied three different Portland cement contents 6%, 9% and 12% in the soil. The results showed compressive strength of up to 5 MPa at 28 days for the types of soil studied with 12% of Portland cement. The authors concluded that 9% of Portland cement in the different soils studied is sufficient to reach the minimum compressive strength required by the NBR 8491:2012 standard. Another stabilization study with Portland cement for BTC was by Bogas et al (2019), two compositions were carried out, both with sandy soil with replacement of 15% of recycled aggregate, one with the addition of 8% of cement and the other with the addition of 4 % cement + 4% lime, concluded that CEB stabilized with 4% cement + 4% lime was sufficient to produce BTC resistant to compression and water absorption.

4.2.1.2 Agricultural Stabilizers

Hany et al (2021) evaluated the use of industrial by-products as partial or total replacement of cement, such as rice husk ash, and concluded that the materials are promising in the production of CEB, as all the bricks produced satisfied the minimum requirements demanded by the Egyptian standard for category A. The replacement of 10% of cement in mass by rice husk ash without any treatment, reached the best value of compressive strength among all evaluated mixtures. Yatawara; Athukorala (2021) recommended replacing at most 7.5% clayey soil with rice husk ash in the manufacture of CEB for non-structural walls. Nshimiyimana et al (2019) studied BTC stabilization with calcium carbide residue either mixed with rice husk ash or without ash and found that rice husk ash accelerates cure in mixed solutions to reach reaction maturity at 28 days compared to calcium carbonate which reached reaction maturation after 45 days. According to Fundi et al (2018), the addition of 1% rice husk ash in a mixture of 3% lime with 6% pozzolanic cement in laterite soil exhibited the highest compressive strength at 28 days. Ferreira; Cunha (2017) evaluated the influence of some plants on the production of

BTC, among some mixtures, rice husk ash was added at 10%, 20%, 30% and 40% to replace the 10% cement content. The 10% rice husk ash content led to the best technical quality.

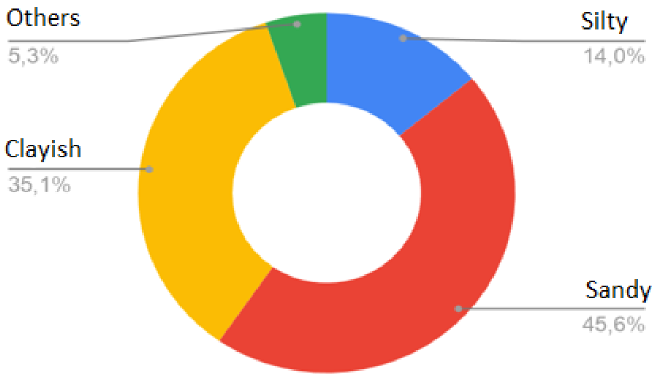
Moura et al (2021) characterized and used sugarcane bagasse ash (SBA) as a supplementary cementitious material in the production of CEB, in proportions of 10%, 20% and 50% by mass. The chemical characterization of SBA indicated the presence of crystalline silica in the form of quartz and cristobalite. The replacement of 20% cement by sugarcane bagasse ash had the highest resistance to simple compression. Jordan et al (2019) evaluated the effect of untreated sugarcane bagasse ash on the compressive strength and water absorption index of CEB. CEBs were produced with additions of 0%, 30% and 40% of sugarcane bagasse ash. The results were 1.27 MPa, 1.3 MPa and 1.88 MPa, and did not reach the minimum values established by the NBR 10834:2012 standard (not even the composition that did not contain sugarcane bagasse ash), which recommends an average compressive strength ≥2.0 MPa and an absolute value ≥ 1.7 MPa.

4.2.2 Soil properties

The characterization of the soil particle size distribution is a fundamental step in evaluating the suitability of the soil for earth construction. The soil is made up of particles of variable size, namely clay, silt and sand (Figure 3), which mix, and their behavior is predicted by the relative presence of these particles (LEITÃO et al, 2017).

In this sample, the predominance is for sandy soils, with 28 studies, followed by clayey (21), silty (9) and others with 3 studies, carried out with quarry fines, aggregate washing process and limestone residue.

Figure 3: Soil classifications



Source: THE AUTHORS, 2021.

Azevedo et al (2019) used soil with a predominance of clay in its composition, 49%; a high percentage of clay is a major problem for BTC, as it favors the appearance of cracks after the hydration process, which affect the effectiveness of the final product, so the author added four levels of sand of 27%, 25, to the mixture. 5%, 24% and 22.5%. In this context, Cottrell et al (2021) needed to correct the soil granulometry of approximately 22% clay, 56% silt and 22% sand, and the guide followed by the author, Earth Masonry: Design and Construction Guidelines, recommends a content between 25% and 50% of sand, with this the author incorporated 20% of sand into the mixture. Serbah et al (2018) corrected with 30% natural sand to meet the normative recommendations.

Kasinikota; Tripura (2021) changed the grain size distribution of the original soil, which was 2.65% sand, 67.21% silt and 30.14% clay, as they were outside the recommended by IS 1725:2013 standards and HB 195:2002 to produce CEB, the standards recommend a sand content of 30–75% and 50–80% respectively. The authors reconstructed the granulometric curve of the soil, with the new configuration in 70.41% of sand, 20.53% of silt and 9.06% of clay. Yatawara; Athukorala (2021) also had soil sample incompatibility with the SLS 1382:2009 standard, the values were 33.9%, 27.8% and 38.3% of silt, clay and sand respectively. The standard recommends 5–20% silt particles, 10–15% clay particles, and 65% sand and gravel particles in a soil sample for CEB. The authors mitigated the problem by stabilizing the soil with rice husk ash and cement. Lavie Arsène et al (2020) incorporated into the soil three types of aggregates - limestone, sandstone and porphyry - to obtain an optimized particle size for CEB.

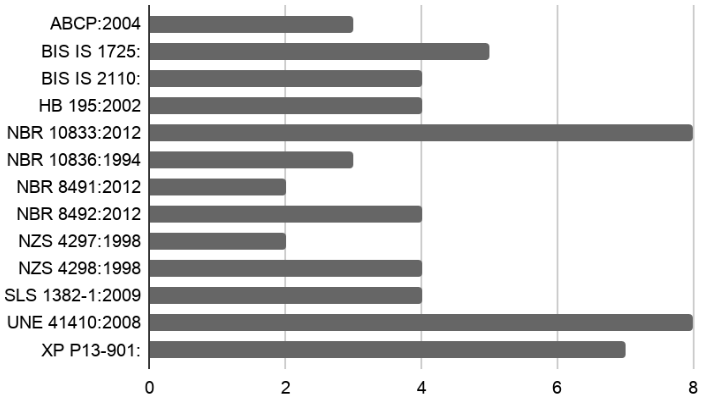
The final strength of the blocks is largely related to the particle size distribution of the soil used to obtain compacted elements with optimal properties, including mechanical strength, low permeability and greater durability. Soils with plasticity indexes between 15% and 30% have a stabilization success rate of 69%, while soils with plasticity index less than 15% have greater stabilization, above 93%, which can be increased to 100% if the soil has a clay/silt percentage between 21% and 35%. On the other hand, a soil with a plasticity index above 30% negatively affects stabilization (RIVERA, 2020).

4.3 Methods for producing CEB

The characterization of the soil particle size distribution is a fundamental step in evaluating the suitability of the soil for earth construction. The soil is made up of particles of variable size, namely clay, silt and sand, which mix, and their behavior is predicted by the relative presence of these particles (LEITÃO et al, 2017).

The most cited standards in the cut are listed in the bar graph (Figure 4) and Table 1 presents their characteristics. The most followed standards for BTC manufacturing in Brazil - NBR 8491:2012 and NBR 10834:2012 - present the requirements for brick and block of soil-cement, while NBR 8492:2012 and NBR 10836:2012 report the test method of determination of compressive strength and water absorption. NBR 10833:2012 demonstrates the manufacturing process of solid brick and hollow block of soil-cement using a hydraulic or mechanical press. Brazilian standards no longer carry out the freeze-thaw durability test, since there is no Brazilian region where this environmental effect has considerable weight (ABCP, 2004).

Figure 4: Most cited standards for CEB production



Source: THE AUTHORS, 2021.

Table 1: CEB production parameters

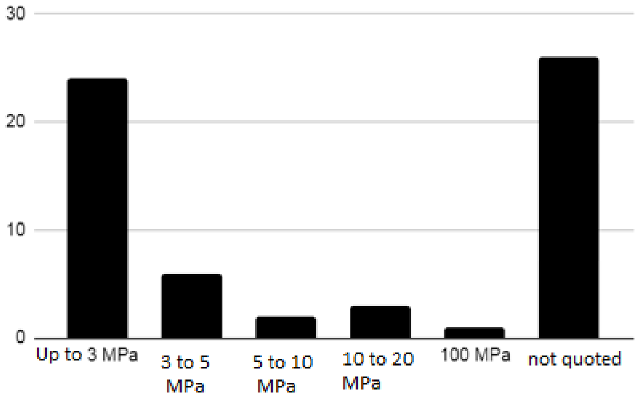
RULE	SOLO		STABILIZER (%)	DIMENSIONS (mm)	COMPRESSION RESISTANCE (MPa)	WATER ABSORPTION (%)	EROSION RESISTANCE	WETTING AND DRYING
NBR 10833:2012 NBR 8491:2012 NBR 8492:2012 BRASIL	LL: ≤ 45%	IP: ≤ 18%	Cement	Type A: 200X100X50	Average ≥2,0	Average ≤ 20	Nothing contained	Nothing contained
	100% ≤ 4,75 mm 10% a 50% ≤ 0,075 mm			Type B: 240X120X70	Individual ≥ 1,7	Individual ≤ 22		
UNE 41410:2008 SPAIN	25% ≤ LL ≤ 50%	5% ≤ IP ≤ 25%	Cement, Lime and Plaster ≤ 15	Manufacturer must determine, provided that it meets UNE-EN 772 16:2001	BTC-C1: 1,3 - BTC-C3: 3,0 - BTC-C5: 5,0	Nothing contained	Suitable block 0 ≤ D ≤ 10	6 cycles: no fissure, cracking, swelling, holes, fragments Efflorescence
	Clay: ≥ 10%; Organic matter ≤ 2% and soluble salts ≤ 2%						Block not suitable D > 10	
XP P13-901:2001 FRANCE	25–50	2.5–29	Hydraulic binder, meet NF P 15 300 and NF P15-301 standards	More common 295x140x95	Dry: BTC 20 ≥ 2 - BTC 40 ≥ 4- BTC 60 ≥ 6	Nothing contained	Nothing contained	Nothing contained
	Gravel: 0-40% Sand: 25-80%; Silt: 10-25% and Clay: 8-30%			220x220x95	Wet: BTC 20 ≥ 1 - BTC 40 ≥ 2 - BTC 60 ≥ 3			
NZS 4298:1998 NEW ZELAND	Nothing contained		Cement ≤ 15	290-300x140x90-102	≥ 1.3 ≥ 3.2	Nothing contained	Index from 1 to 5: 0 ≤ D < 20 20 ≤; D < 50; 50 ≤ D < 90; 90 ≤ D < 120 D ≤ 120	6 cycles: no crack, crack, swelling, holes, fragments Efflorescence
SLS 1382-1:2009 SRI LANKA	IP ≤12		Cement	230x110x75; 240x115x90; 290x140x90; 220x140x130; 220x220x130	Dry: Grade 1: ≥6; Grade 2: ≥4≤6; Grade 3: ≥2.8≤4	<15	<10 mm	Nothing contained
	Sand + gravel > 65%; Silt 5% 20%				Wet: Grade 1: >2.4; Grade 2:			

	and Clay 10% - 15%			>1.6 ≤ 2.4; Grade 3: >1.2 ≤ 1.6			
BIS IS 1725:2013 INDIA	LL ≤ 30 Clay: 5-18%; Silt: 10-40%; Sand: 50-80% and Gravel: 0-10%	cement and lime	190X90X90 190X90X40 290X190X90 290X140X90 240X240X90	3.5	≤ 18	Nothing contained	Nothing contained

Source: THE AUTHORS, 2021

The compaction energy applied in the manufacture of BTC is important, as it directly influences the strength and durability of the blocks. Hany et al (2021) demonstrated this issue through two different compaction pressures, 9 MPa and 16 MPa, the results were 6.99 and 8.58 N/mm² respectively, therefore increasing the compaction pressure increases the resistance to compression by about 22.7% due to the decrease in void content. Elahi et al (2021) demonstrated that with increasing compaction energy from 3.33 Kg/cm2 to 7.77 Kg/cm2, there is an increase in sample density from 4 to 9%, depending on the added amount of ash and the compressive strength is significantly improved from 15 to 29%. Bruno et al (2017) applied a super energy of 100 MPa and obtained as a result block with a compressive strength of 14.6 MPa. The authors also reported that block stiffness and strength tend to increase as loading time during fabrication increases by up to 20 minutes. For longer settling times, stiffness and strength remain virtually unchanged. This suggests that while a very long set time is generally unnecessary, a quick compaction of just a few seconds, as is often the case in current construction practice, cannot guarantee the best mechanical properties. In general, the studies use a load of at most 5 MPa, which is consistent with manual and mechanical presses, with hydraulic or manual operation, available on the market. 24 studies do not directly cite the compaction energy, however they reference a standard or equation (Figure 5).

Figure 5: Energy of compression



Source: THE AUTHOS, 2021.

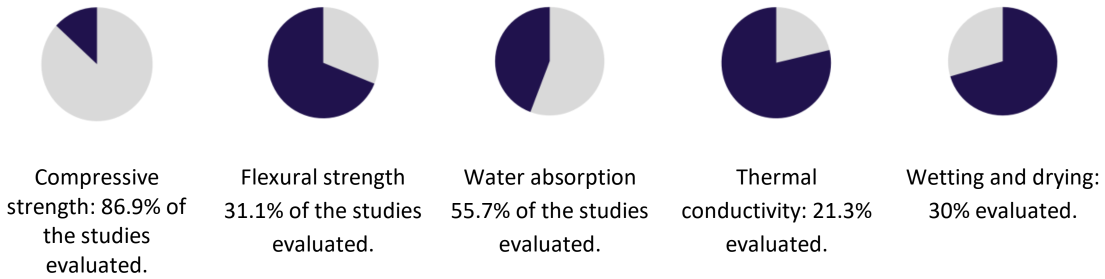
To determine the amount of water to produce CEB, the proctor test is performed, which results in the moisture content at which the maximum dry density of the mixture is reached by a given compaction effort (ELAHI et al, 2020). In addition to the proctor test, other techniques are also used, Sekhar and Nayak (2018) performed the Drop ball test to obtain the amount of water needed to acquire a good quality block, in turn, HANY et al (2021) used the test as per the guidelines of the Australian Earth Building Guide. The SLS 1382:1 standard mentions that the moisture content must be less than 15% and the dry density must be greater than 1,750 kg/m3.

The most commonly used block size in the cutout is 290-300 (mm) length × 140 (mm) width × 95-100 (mm) height, with 17 studies. The choice of BTC geometry is an important factor, as according to Cottrell et al (2021) it influences the mechanical strength of the block. In an experiment with solid blocks, blocks with recess on the surface and perforated blocks, with dimensions of 300x150x90 mm, the solid block exhibited greater resistance to compression and bending with 6.73 MPa and 1.31 MPa, respectively, whereas the solid block with recess exhibited the lowest compressive and bending strength with 3.74 MPa and 0.63 MPa, respectively.

4.4 Performance evaluation

The data extracted from the standards unanimity, the mandatory evaluation of compressive strength, however, in the present sample of 61 articles, 8 of them did not evaluate (Figure 6), as the authors focused on the durability performance, for example, Nshimiyimana et al (2021) carried out tests of wetting and drying cycles, capillary water absorption, total water absorption, resistance to water erodibility and abrasion resistance, the author Danso (2017) opted for the accelerated erosion test, in turn Bezerra and Azeredo (2019) studied the influence of capillary absorption time and the concentration of sulfate ions in BTC exposed to sulfate attack. Giorgi et al (2018) evaluated the BTC on two parameters of the Brazilian performance standard (NBR 15575), habitability (rain watertightness factor and water permeability) and sustainability (durability factor) with the performance of the action test of heat and thermal shock. In another study by the authors Nshimiyimana et al (2019) mentioned that when there is no total mass loss without fragmentation or cracking, monitoring of mechanical strength is recommended. Another bias that was addressed without taking into account compressive strength is the investigation of thermal conductivity, for the studies by Saidi et al (2018); Balaji et al (2017); Leitão et al (2017).

Figure 6: CEB Performance Evaluation



Source: THE AUTHORS, 2021.

Compressive strength and water absorption are the most significant properties and most frequently used by several researchers to assess the suitability of CEBs in construction (ISLAM et al 2020). The Brazilian standard NBR 8492:2012 mentions only the two tests. For this reason, the main results of the surveys that evaluated the compressive strength and water absorption will be presented in detail.

4.4.1 Compressive strength

Compressive strength is generally accepted as a universal property for determining CEB quality. In general, it is related to the type of soil, the type and quantity of stabilizers, the pressure and the compaction process (Rivera et al, 2021; Teixeira et al, 2020; Elahi et al, 2020; Islam et al, 2020).

Wet and dry compressive strength tests are conducted with the block between the load plates with plywood sheets or steel plates ranging from 9mm to 15mm in thickness, to ensure an evenly distributed load across the specimen. For the dry strength test, the samples are oven dried to constant mass and for the wet strength test, the samples are immersed in water for 24 hours or 6 hours, depending on the technical standard.

Hany et al (2021) performed the test for three block states: as received, oven dried to constant weight and moist by immersion in water for 24 h. The results showed that at 28 days of age, the dry block had greater resistance than those received, at around 4-29%. For wet BTC, there was a decrease of 2.5% to 41% compared to those received. The increased strength of the dry block is attributed to the increase in forces between the gel particles due to the removal of water content as a result of the drying process. Elahi et al (2020) made the same finding in the increase in strength due to the presence of C-S-H gel (hydrated calcium silicate) which is formed due to the reaction between cement and soil, and this gel fills the pores providing greater strength.

Furthermore, Rivera-Gómez et al (2021) and Teixeira et al (2020) observed a direct correlation between the results of BTC dry bulk density and mechanical performance, the higher density obtained by compaction significantly increases the compressive strength of the blocks, however the authors emphasize attention to soil shrinkage and healing problems.

Therefore, to obtain a good result of compressive strength, a series of control measures considered in the manufacture of blocks must be assigned, such as mixing design, water content, material dosage and compaction pressure (Cottrell et al, 2021).

4.4.2 Water absorption

To assess water absorption, the blocks are completely dried in an oven maintained between 100 to 105 °C, then their masses are recorded, after weighing the blocks are immersed in water for 24 hours, then they are weighed again to determine their water absorption. The maximum allowed limit varies according to technical standards, in general from 15% to 20% (Sravan et al 2017; Seco et al 2017; Barros et al, 2020).

According to Nshimiyimana et al (2021) the most challenging indicator of the durability and stability of CEB is water absorption, which can negatively affect mechanical strength in wet conditions. González-López et al (2018) demonstrated that water absorption is related to the type and content of stabilizers. The lime-stabilized samples absorbed similar amounts of water for the different forces used to compact. In contrast, the samples stabilized with cement absorbed less water and the compaction action with greater force resulted in a decrease of up to 38%. Also observed by Sekhar and Nayak (2018) where water absorption decreases with increasing cement content. This was due to the reduction of void spaces between the soil particles that were filled by the gel formation of pozzolanic products and cement hydration. The authors also reported that the decrease in water absorption from the stabilized blocks is due to the interactions of cement with aluminum silicates present in the soil, thus reducing voids. Fundi et al (2018) produced CEB with laterite soil, and indicated that the increase in cement dosage led to a reduction in water absorption, as the cement unites the laterite particles, reducing pore sizes. The authors also reported that hydrated lime is used in soil modification, as calcium ions from hydrated lime migrate to the surface of clay particles and displace water and other ions. This has the effect of drying out the soil through flocculation of the particles. The results show that the addition of 2% lime in the presence of 6% cement has a positive effect on increasing the water absorption resistance of the blocks.

Rivera et al (2021) mentioned that the properties of the blocks are closely linked to the type of soil used, with the soil texture being a very important parameter for the manufacture of CEB. In this context, Seco et al (2017) observed a significant difference for the water absorption values, which decreased with increasing sand percentage. As the percentage of sand in the samples increased, capillary water absorption was faster, but as sand has a lower affinity for water than clay, the total amount of water absorbed was lower. Santos et al (2020) observed that for compaction of clayey soil a greater volume of water is needed, however there was a slight decrease in water absorption when the cement content increased in the soil. Lavie et al (2020) reduced soil water uptake by replacing clay with lower water uptake aggregates.

Another factor observed about the water absorption test by the authors Gutiérrez-Orrego et al (2017) is that the water absorption did not change detectably when the immersion time was increased from 24 h to 96 h, as it had an increase in only 1% after 96 h of immersion in water.

Finally, it is noteworthy that the water absorption capacity of BTCs is not only affected by the type and quantity of stabilizers, but also the type of soil, in addition to production parameters such as compaction pressure and curing conditions, therefore, the final water absorption capacity of blocks can be controlled by optimizing initial production and curing conditions (Nshimiyimana et al, 2020; Jordan et al, 2019; França et al, 2018).

5 FINAL CONSIDERATIONS

The research from 2017 to 2021, in three databases - Scopus, Web of Science and SCIELO - gathered data relevant to the production of compressed earth blocks (CEB) highlighted below.

The interest in researching CEB is all over the world, from developing countries such as Brazil, China and India, to developed countries such as Spain, Portugal, England, France and the USA. Approximately 51% of the sample of documents studied were published in Construction and Building Materials. The most cited author of the period was Sekhar; Nayak (2018) with 36 citations in Scopus and 27 in Web of Science.

There are currently concerns about the use of Portland cement to stabilize BTC, due to the high rates of CO2 generated during cement production, therefore, there was an increase in studies that used other stabilizers. About 18% of the studies used agricultural by-products, such as rice husk ash and sugarcane bagasse ash, and another 15 studies used mineral residues, such as granulated blast furnace slag, metakaolin, silica fume, calcium carbonate residue, especially fly ash, with 9 studies, for partial or total replacement of Portland cement.

Soils with plasticity indexes between 15% and 30% have a stabilization success rate of 69%, while soils with plasticity index less than 15% have a stabilization greater than 93%, which can be increased to 100% if the soil have a clay and silt percentage between 21 and 35%. Soil corrections can be made to improve the quality of the BTC produced. The SLS 1382:1 standard mentions that the moisture content must be less than 15% and the dry density must be greater than 1,750 kg/m3.

Block geometry influences the mechanical strength of CEBs, solid blocks exhibit greater compressive strength compared to solid blocks with recess or holes. The compaction energy applied in the manufacture of CEB is very important, as it influences the strength of the blocks, with an increase in the compaction energy, an increase in density and resistance to compression and a decrease in water absorption is obtained.

Compressive strength is generally accepted as a universal property for determining CEB quality. In general, compressive strength is related to the type of soil, the type and quantity of stabilizers, the pressure and the compaction process. Finally, the most challenging indicator of CEB durability and stability is water absorption.

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