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Criteria to assess the flow of cement-stabilised self-compacting earth

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ABSTRACT. The cement-stabilised self-compacting earth (CSCE) is composed of the mixture of soil, cement, water and superplasticiser admixture and has a suitable physical-mechanical behavior for application as a construction and building material. There are no guidelines or specific standards for the characterization tests of CSCE in the fresh state. Thus, the study determined criteria to assess the flow of CSCE for application in monolithic wall. The dosage of CSCE mixtures was evaluated to achieve minimum mechanical strength for use in earthen construction; selecting the fluidity ranges of the CSCE mixtures by means of the liquid limit of soils and the linear shrinkage test, and the application of the physical tests: Slump Test, Slump Flow and Flow Table in the fresh state of CSCE mixtures. The results indicated that soils with predominant sandy or clayey characteristics are compatible to obtain a stable CSCE. The adapted Slump Flow test is recommended to assess the fluidity of CSCE and the range of 320-460 mm for the spread diameter of the mixtures is an adequate criterion for guaranteeing the occurrence of the necessary flow of the CSCE mixture without segregation and exudation in the fresh state.

Keywords: construction material; sustainability; soil-cement; earthen construction.

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Introduction

In the search for more efficient building material alternatives, the cement-stabilised self-compacting earth (CSCE) has emerged, which is composed of soil, cement stabilizer, superplasticiser admixture and water, and which may contain fibers or other mineral additives. Its consistency must be fluid (liquid) in order to mold itself without the need for mechanical compaction and the mixture must not present segregation or exudation for the proper application and performance in construction elements.

Construction techniques that use the soil in the plastic or liquid consistency to manufacture bricks/blocks, construction of monolithic wall, as well as filling of support structures are attempted yet again, but this time using less water based on the addition of chemical admixture and stabilizer.

According to Cristelo, Glendinning, Miranda, Oliveira, and Silva (2012), the main advantages of the construction system with CSCE are: the elimination or reduction in energy consumption (compaction, vibration or pressing) during its application; and greater stability of the mix soil+cement stabilizer+water+superplasticiser admixture based on the smallest amount of water, which will control the separation of soil particles in the fresh state and appearance of shrinkage cracks in the structures.

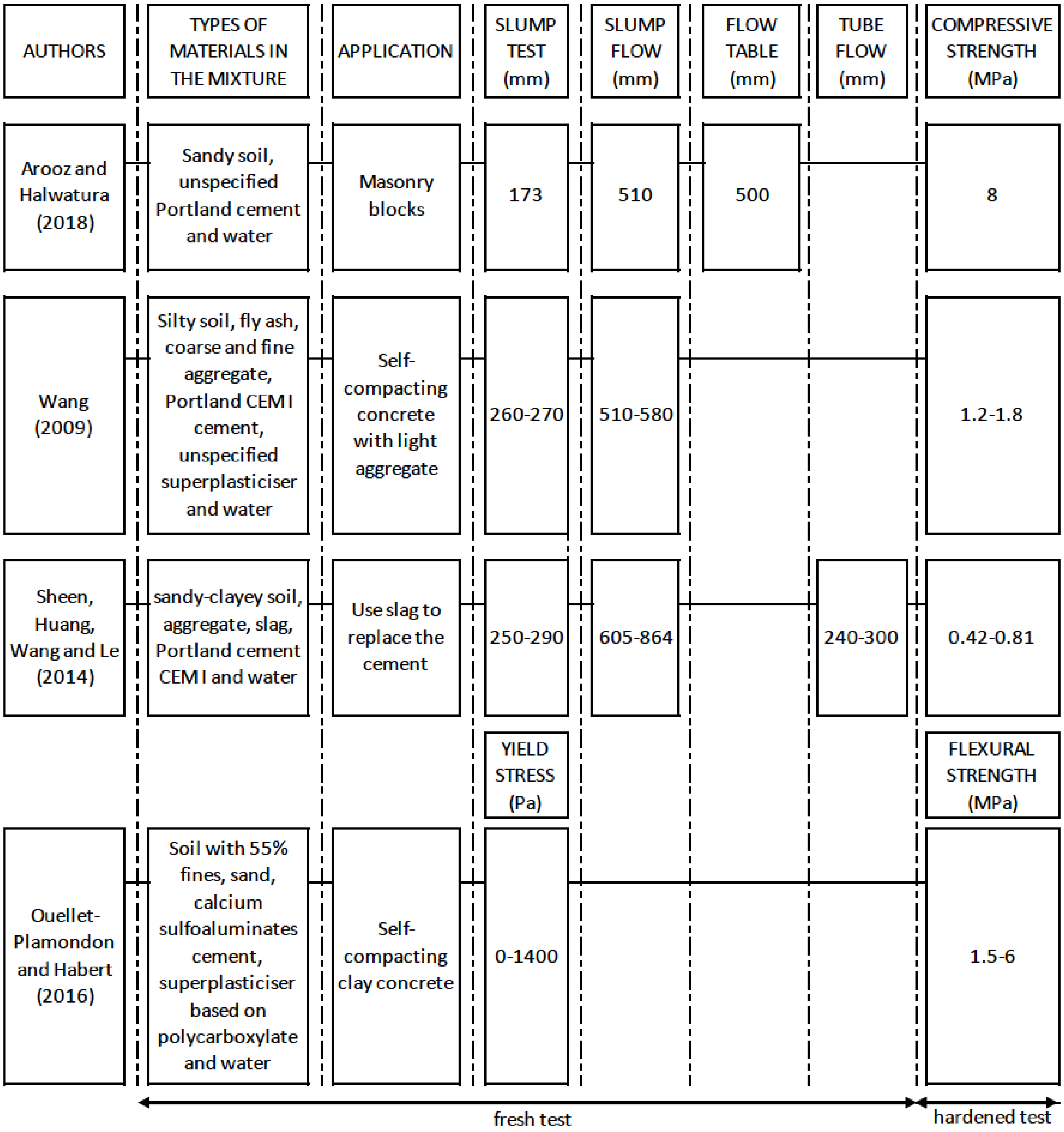
Soil as a building material has already been studied and proven for its effectiveness, and the advantages of using soil in construction systems stem from the lower cost of embedded energy during its life cycle stages, highlighting: extraction (reduces related transport costs), manufacturing (easily obtained manual or mechanized processes), use (great capacity to regulate the hygrothermal conditions of the environments) and disposal (allows to be recycled without damaging the quality of the final material) (Pacheco-Torgal & Jalali, 2012; Sameh, 2014; Udawattha, Galabada, & Halwatura, 2017).

Various types of soils can be used to compose the CSCE, however, to achieve flow the soil should fundamentally have the presence of fines (silts + clays). According to Milani and Silva (2019), there is a minimum water limit for the fluidization of silts and clays in the soil for the occurrence of shear between the particles, and this limit must be in accordance with the liquid limit (LL) of the soil, that is, LL is the amount of water needed, allowing the fines to become viscous.

Cerny, Kocianova, and Diederichs (2017) affirm that the most important parameter to be evaluated in a mixture of soil in the liquid consistency is the LL and the deformation modulus, and based on the LL, the soil can be classified according to the plastic and the deformation modulus, which determines the soil's compression capacity.

Therefore, the starting point for the CSCE dosage is to establish the water content for the soil+cement+superplasticiser to reach the desired liquid consistency, considering the soil as the system matrix for determining the self-compaction of CSCE. Considering these studies for the ideal conditions of fluidity and mechanical strength of CSCE for application as a building material, Figure 1 contains a research summary on CSCE using different types and dosages of materials, and physical-mechanical characterization tests of cement composites in the fresh and hardened state.

It is observed that there is no similar parameter between the tests mentioned for the specific production of CSCE, where each researcher establishes an ideal value or criterion according to the following situations: types of materials used in the CSCE dosage study; characterize CSCE based on analogies with tests for self-compacting concretes and cementitious mortars; and define the CSCE based on the potential and limitations of its use in construction systems.



AUTHORS	TYPES OF MATERIALS IN THE MIXTURE	APPLICATION	SLUMP TEST (mm)	SLUMP FLOW (mm)	FLOW TABLE (mm)	TUBE FLOW (mm)	COMPRESSIVE STRENGTH (MPa)
Arooz and Halwatura (2018)	Sandy soil, unspecified Portland cement and water	Masonry blocks	173	510	500		8
Wang (2009)	Silty soil, fly ash, coarse and fine aggregate, Portland CEM I cement, unspecified superplasticiser and water	Self-compacting concrete with light aggregate	260-270	510-580			1.2-1.8
Sheen, Huang, Wang and Le (2014)	sandy-clayey soil, aggregate, slag, Portland cement CEM I and water	Use slag to replace the cement	250-290	605-864		240-300	0.42-0.81
			YIELD STRESS (Pa)				FLEXURAL STRENGTH (MPa)
Ouellet-Plamondon and Habert (2016)	Soil with 55% fines, sand, calcium sulfoaluminates cement, superplasticiser based on polycarboxylate and water	Self-compacting clay concrete	0-1400				1.5-6

Figure 1. Summary of tests applied on CSCE by authors: Arooz and Halwatura (2018); Wang (2009); Sheen, Huang, Wang, and Le (2014); Ouellet-Plamondon and Habert (2016).

This corroborates the lack of guidelines for the characterization tests of CSCE in the fresh state and, consequently, the standardization difficulty to attest the self-compaction of cement-stabilised self-compacting earth and the dissemination of its use. Thus, the study determined criteria to assess the flow of CSCE for use as constructions material and to identify the most suitable physical tests to be applied in CSCE mixtures for its characterization in the fresh state.

Material and methods

The materials used in this study were: three Brazilian tropical soils termed sandy soil, silty-clay soil and clay soil, according to the predominant particles; Portland cement composed with 6-14% pozzolan CPII Z; and polycarboxylate-based superplasticiser admixture MasterGlenium ACE 409 of BASF S.A.

CSCE dosage study

A particle-size composition analysis, as well as soil plastic and liquid limits, was carried out for classification according to the criteria of the American Association of State Highway and Transportation Officials (AASHTO) and verification of the influence of physical characteristics on the CSCE fluidity process.

In view of the lack of standardized procedures for CSCE, the dosage study for choosing the reference trace of the soil:cement:superplasticiser admixture for each type of soil considered the spreading diameter of the CSCE mixture, in the Slump Flow test, between 660 and 750 mm, because according to ABNT NBR 15823-2 (*Associação Brasileira de Normas Técnicas* [ABNT], 2017) this is the range required for applying self-compacting concrete in monolithic concrete walls. This construction system is similar to the CSCE monolithic wall.

Another factor considered was compressive strength of the CSCE mixture at 7 days (ϕ50 mm^2 x h=100 mm specimens), equal to or greater than 1 MPa, as this is a requirement of international norms for the minimum mechanical performance of constructions with cement stabilised rammed earth (Maniatidis & Walker, 2003).

The dosage of the CSCE mixture with more soil and less admixture content is ideal because the insertion of cement agents in the soil liquid consistency must correspond to a minimum addition used in the specific material, and in fact, the optimum stabilizer content corresponds to the limit of the economic and environmental investment of the final CSCE product.

Selection of CSCE fluidity ranges

The influence of water content on the process of fluidity and shrinkage by drying the CSCE mixtures was evaluated using the method described by the Research and Development Center to verify the linear shrinkage of a given soil (Neves, Faria, Rotondaro, Salas, & Hoffmann, 2010).

Various percentage of water was added to the soil (range 20 to 58%), as well as the content of cement and superplasticiser admixture defined in the dosage study carried out in the previous stage.

This mixture was cast into a 60 cm length x 8.5 cm width x 2.5 cm depth wooden box, without compaction, vibration or pressing. After 7 days, in a controlled humidity and temperature environment, the shrinkage values of all sides of the box were added, corresponding to the total shrinkage of the evaluated mixture. The total linear shrinkage of the mixture must be less than or equal to 20 mm, and there should be no cracks and/or fissures. Thus, this limit corresponds to the ideal mixture to avoid the occurrence of material shrinkage when applied as construction material.

This analysis resulted in the definition of the fluidity range (FR) for each CSCE mixture. FR is range the water percentages to be added to the mixtures in order to maintain the CSCE fluidity in the fresh state with the occurrence of shrinkage during drying within the limits established for building elements of construction works.

Execution of CSCE experimental tests

For the analysis of the most adequate experimental tests for flow study CSCE mixtures in the fresh state, the physical-mechanical tests were performed for each CSCE mixture within its respective fluidity range (FR) determined in the previous stage. The water addition factor within the FR of the mixture was at every 1%. Based on Figure 1, the tests applied to CSCE mixtures in the fresh state were the Slump Test, Slump Flow and Flow Table; and in the hardened state, the simple compression test was applied at 28 days on specimens of ϕ50 mm2 x h=100 mm (ϕ=specimens diameter, h=specimens height) dimensions for the evaluate soil-cement stabilisation.

It is noteworthy that for executing the Slump Test and Slump Flow, the Abrams Cone was used, but with reduced size, as shown in Figure 2. Wedding and Kantro (1980) developed the Slump test method with reduced size, called mini-Slump, in order to evaluate cement pastes with the presence of superplasticiser admixtures. This method is adopted in national and international studies, as it can be performed using a reduced amount of material, reaching the same results found in the Slump Test. In turn, Tan, Bernal, and Provis (2017) investigated the influence of the mini-Slump on the workability of cementitious pastes and the conclusion was obtained by comparing the results of the mini-Slump with predicted values in numerical modeling. According to Tan et al. (2017), this method proved to be applicable and reproducible and with the potential to better observe the behavior in the fresh state of the mixture.

In relation to the statistical treatment, the obtained results in the experimental tests was evaluated by the analysis of variance (ANOVA) and Tukey's test, checking whether the treatment means are statistically equal, and for this, the F value must be close to 1.0 and the p value greater than 0.05. Five replications were used for each CSCE treatment. For the Tukey test, same lower case letters on the same line do not differ.

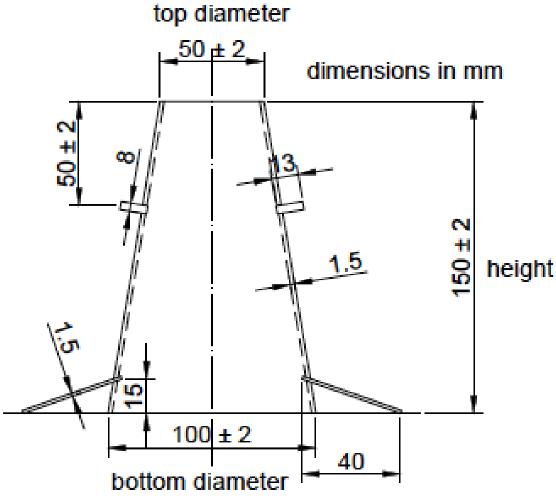


Figure 2. Abrams cone with reduced dimensions.

Results and discussion

Soil characterization and dosage study

The characterization of soils showed that the sandy soil, despite not having defined liquid and plastic limits, contains sufficient content of fines for molding construction elements. The silty-clay and clay soils were classification as A-7-5, however silty-clay soil presented a more presence of silt in its particle size composition (Table 1).

Table 1. Soil characterization.

Soil characteristics		Sandy soil	Silty-clay soil	Clay soil
Particle Size Composition	Coarse sand (0,60 - 2,00 mm)	1.00	4.53	1.90
	Medium Sand (0,20 - 0,60 mm)	41.00	16.10	12.70
	Fine sand (0,06 - 0,20 mm)	36.45	26.29	12.53
	Silt (0,002 - 0,06 mm)	7.83	25.03	19.95
	Clay (< 0,002 mm)	13.73	28.05	52.90
	Material passing through the sieve 4,8 mm (%)	100	100	100
	Material passing through the sieve 0,075mm (%)	24.00	66.75	76.22
	Specific solids mass (g cm^{-3})	2.84	2.82	3.77
Atterberg limits	Liquid Limit (%)	NL	51.08	54.86
	Plastic Limit (%)	NP	38.61	30.96
	Plasticity Index (%)	NP	12.47	23.90
Classification	AASHTO	A-2-4	A-7-5	A-7-5

Helson, Beaucour, Eslami, Noumowe, and Gotteland (2017) explained that the similar presence of silt and clay fraction can cause soil instability, since silts are solid in a flat or polyhedral shape that present little or no plastic and provide a decrease in internal friction due to the rearrangement of particles when they experience compaction. And still for clayey soil, the predominance of clay minerals will also suggest high water content, as the clay contains a large specific area due to its size, thus retaining more water in its structure, generating high capillary porosity and lower mechanical strength.

The dosage study to determine the reference CSCE mixtures (Table 2) showed minimal mechanical performance with the sandy and clayey soils and needed a greater amount of cement and superplasticiser in the CSCE mixture with clay soil to reach strength of 1 MPa at 7 days. For CSCE mixtures with silty-clay soil, regardless of cement and superplasticiser content, the minimum mechanical strength was not achieved. As according to Teerawattanasuk and Voottipruex (2014), this can be explained because the silt particle although its chemical composition is similar to sand grains, its morphology has more pores between the particles, retaining more water and allowing the formation of cracks in the set due to the lack of plastic.

Therefore, the reference dosages adopted for the flow study of CSCE mixtures were 1:8 (cement: sandy soil, in mass, with 0.8% of superplasticiser) and 1:6 (cement: clay soil, in mass, with 1.2% of superplasticiser).

Table 2. Dosage study for choosing the CSCE reference.

Soil		CSCE					
	Dosage (cement: soil: % admixture, by mass)	1:8: 0.8	1:8: 1.2	1:10: 0.8	1:10: 1.2	1:12: 0.8	1:12: 1.2
	Cement consumption (kg m^{-3})	177.3	164.8	144.2	149.0	112.0	117.0
Sandy	Compressive strength at 7 days (MPa)±ASD (CV)	1.115±0.16 (14.34)	0.885±0.25 (28.24)	0.771±0.09 (11.67)	0.667±0.03 (4.49)	0.656±0.06 (9.14)	0.636±0.03 (4.71)
	Average spread (mm)	750	690	710	710	660	750
	Water content (%)	28	33	28	26	34	31
	Dosage (cement: soil: % admixture, by mass)	1:4: 0.8	1:4: 1.2	1:6: 0.8	1:6: 1.2	1:8: 0.8	1:8: 1.2
	Cement consumption (kg m^{-3})	238.7	235.6	202.5	206.2	172.4	172.3
Silty-clay	Compressive strength at 7 days (MPa)±ASD (CV)	0.465±0.02 (4.30)	0.451±0.02 (4.43)	0.269±0.04 (14.86)	0.242±0.03 (12.39)	0.189±0.03 (15.87)	0.109±0.00 (3.67)
	Average spread (mm)	670	690	730	700	680	680
	Water content (%)	49	50	36	34	29	29
	Dosage (cement: soil: % admixture, by mass)	1:6: 0.8	1:6: 1.2	1:8: 0.8	1:8: 1.2		
	Cement consumption (kg m^{-3})	176.7	195.2	164.9	144.1		
Clay	Compressive strength at 7 days (MPa)±ASD (CV)	0.834±0.06 (7.19)	1.247±0.19 (15.23)	0.512±0.07 (13.67)	0.474±0.04 (8.43)		
	Average spread (mm)	730	670	670	680		
	Water content (%)	53	46	40	50		

ASD: Average Standard Deviation; CV: Coefficient of Variation (%).

Selection of fluidity range for CSCE mixtures

The sandy soil+cement+superplasticiser mixtures was based on a 20% water addition, because, according to the Casagrande Plastic Chart, this is the minimum value for the occurrence of liquid of cohesive soils in the Atterberg tests. The CSCE samples with 20 and 22% water addition, due to the low amount of water, presented cracks in 2/3 of the sample and shrank 7 mm. In the CSCE sample with 24% water addition, cracks appeared throughout the entire sample and shrank 6 mm, and with 32 and 34% water addition, the CSCE samples were slightly moist at 7 days of drying. The other samples did not show cracks/fissures and presented the acceptable limit for the linear shrinkage test, thus indicating the FR between 24 and 34% of water for CSCE with sandy soil (Figure 3).

However, the clay soil has an LL of 54.86 and so it started to 52% of water addition to study the flow of the clay soil+cement+superplasticiser mixtures. There was no shrinkage and/or cracking in the CSCE samples, there was, however linear shrinkage in the 52 and 56% water content, which was above the 20 mm limit and the linear shrinkage was within what is stipulated only in the sample with 54% water addition, coinciding with the LL value of the clayey soil. In the CSCE sample with 58% water addition, water segregated from the rest of the mixture, remaining on the surface and causing the test to be discontinued. Thus, the FR of 52 to 56% of water was adopted for the CSCE with clay soil.

Through the linear shrinkage test in the box it was observed that the LL of the soil can be used to perform the initial dosage study of the CSCE mixture, which is better observed in the CSCE mixtures with clay soil, in which only the addition of water, according to the LL of the soil, did not show linear shrinkage during the test. This allows the final material to reach the desired liquid consistency, without any segregation and exudation in the fresh state, and a lower water/cement ratio, which helps to achieve better mechanical performance.

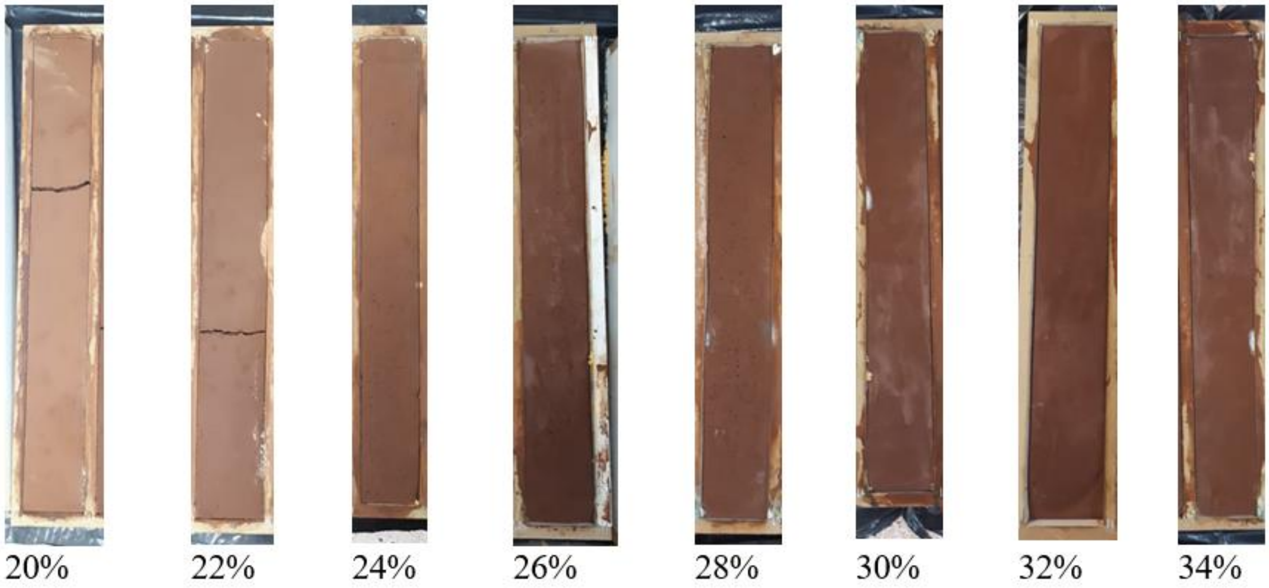


Figure 3. Linear shrinkage test of the box - % of water for CSCE with sandy soil.

On the other hand, for soils that do not have well-defined liquid limit (LL) and/or plastic limit (PL) it is not possible to follow the same criteria for the initial CSCE dosage study, that is, it is uncertain starting in the optimum water content at the initial dosage. In this situation, it is recommended to perform the linear shrinkage test, according to the presented method, in order to determine the range for adding water to the CSCE mixture, which showed no cracks and fissures, and the total shrinkage was less than 20 mm after drying.

The linear soil shrinkage test indicates its behavior concerning the volumetric shrinkage of cement-stabilised self-compacting earth when applied to building construction systems. This movement, caused by the shrinkage, produces cracks in the construction element and allows the penetration of water, and the consequent occurrence of pathological manifestations that are decisive for the loss of strength of the final material (Neves et al., 2010). Knowing the physical performance of stabilized soil through the shrinkage test indicates whether the soil has potential to be used as a construction material matrix (Maniatidis & Walker, 2003).

CSCE experimental tests

Table 3 and 4 show the results of CSCE mixtures in the Slump Test, Slump Flow, Flow Table and Compressive strength at 28 days as a function of the water content of the fluidity range (FR) of the CSCE mixtures with sandy and clayey soils.

For sandy soil, there was a significant increase in the drop height values of the CSCE mixture in the Slump Test in the FR, from 24 to 26%. This is due to the fact that the mixture consistency is relatively dry and, as a result, lower workability. In the FR of 27 to 34%, the mixtures did not change in the drop height values, which characterized the passage of the sandy soil from the plastic state to the liquid.

The other flow tests applied to the sandy soil showed an increase in the spreading diameter values of the CSCE mixture according to the increase in water addition. In the FR of 30 to 34%, the increase in the spreading diameter value of the CSCE mixture in the Slump Flow test, according to the water content increase, was relatively smaller when compared to the FR of 24 to 29%, tending to instability of the spreading mixture due to excess water and exudation. That is, in the Slump Flow test for CSCE mixtures with sandy soil, with water additions above 30%, there was a separation of excess water from the CSCE mixture (Figure 4), resulting in a non-significant interference in the spreading of these mixtures.

For the CSCE mixtures with clay soil, the drop height values in the Slump Test remained stable, showing FR height constancy of 52 to 56%, and the same behavior of the CSCE mixtures with sandy soil in the range of 27 to 34%, since in these ranges, regardless of the type of soil, CSCE mixtures are among in the limit of plastic and liquid state of that soil.

Table 3. Results of the Slump Test, Slump Flow, Flow Table and compressive strength tests - CSCE with Sandy Soil.

Tests		Water content of fluidity range - FR (%)										
		24	25	26	27	28	29	30	31	32	33	34
Slump Test	Average	70	110	140	145	145	145	145	145	145	145	145
	(mm) Teste Tukey	a	b	c	d	d	d	d	d	d	d	d
Slump Flow	Average	123.33	196.67	253.33	316.67	360	400	473.33	480	490	496.67	500
	(mm) Tukey Test	a	b	c	d	e	f	g	gh	gh	h	h
Flow Table	Average	335	241.67	350	360	366.67	383.33	400	403.33	406.67	413.33	415
	(mm) Tukey Test	a	ab	abc	bcd	cde	ef	fg	fg	g	g	g
Compressive strength at 28 days (MPa)	Average	5.39	3.91	3.17	2.65	2.07	2.00	1.99	1.90	1.80	1.78	1.75
	(mm) Tukey Test	a	b	bc	bc	c	c	c	c	c	c	c

Table 4. Results of the Slump Test, Slump Flow, Flow Table and compressive strength tests - CSCE with Clay Soil.

Tests		Water content of fluidity range - FR (%)				
		52	53	54	55	56
Slump Test	Average (mm)	145	145	145	145.67	146.67
	Tukey Test	a	a	a	a	a
Slump Flow	Average (mm)	318.33	393.33	441.67	465	483.33
	Tukey Teste	a	b	c	d	d
Flow Table	Average (mm)	340	354	375	381.67	391.67
	Tukey Test	a	a	b	b	b
Compressive strength at 28 days (MPa)	Average (mm)	0.98	1.01	1.04	1.04	1.02
	Tukey Test	a	a	a	a	a

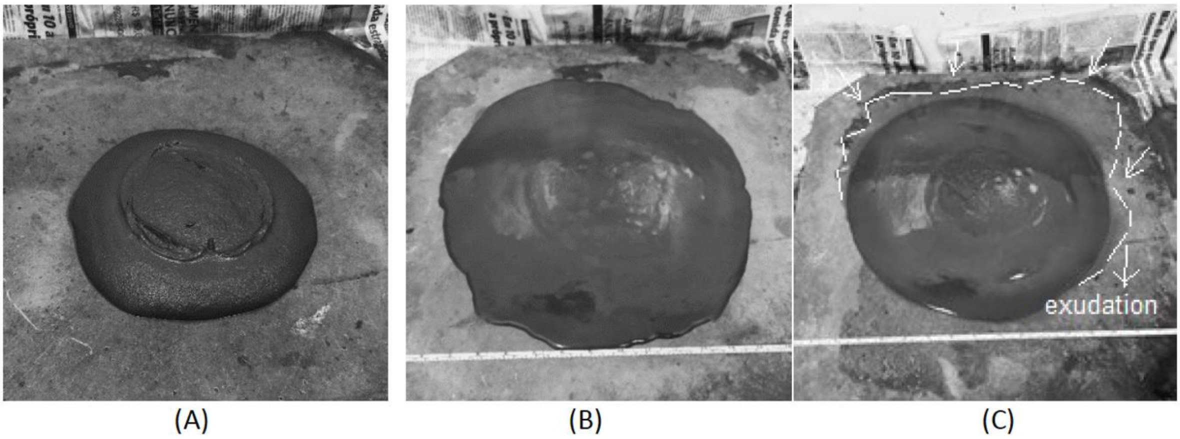


Figure 4. Behavior of CSCE with sandy soil in the fresh state: (A) 24 water addition; (B) 26 water addition and (C) 30% water addition.

For the Slump Flow and Flow Table tests applied in the CSCE mixtures with clay soil, the spreading diameter values of CSCE mixtures increased as much as the increase in the added water content. There was a significant increase in the spreading diameter value in the Slump Flow test in the FR from 52 to 54%, however it was relatively greater when compared to the 55 to 56% FR, where in this range the CSCE mixtures showed spreading instability due to exudation, and therefore not significantly interfering with the spreading diameter values of these mixtures.

Performing the statistical analysis for the CSCE mixtures with sandy soil showed that the averages of the Slump Flow results for the FR of 30 to 34% did not differ significantly from each other, that is, the spreading diameter values above 467.56 mm (corresponding to 473.33 mm - Average Standard Deviation) should not be considered, as they are not statistically reliable.

As for the CSCE mixtures with clay soil, it was found that the average results for the Slump Flow in the FR of 55 to 56% did not differ significantly from each other, that is, the spreading diameter values above 460 mm (corresponding to 465 mm - Average Standard Deviation) should also not be statistically considered.

These statistical findings indicate that in the Slump Flow test the maximum spreading diameter values suitable for CSCE mixtures with sandy and clay soil are 467.56 and 460 mm, respectively. This behavior can be qualitatively confirmed, where in the same fluidity range of each soil (FR of 30 to 34% for CSCE with sandy soil and FR of 55 to 56% for CSCE with clay soil) there was instability of the CSCE mixtures due to segregation and/or exudation.

Observing the procedures performed in the Slump Test, the drop height of the CSCE mixture with sandy soil remained unchanged above the FR of 27%, and from this point on, the constancy of the 145 mm drop height value can be considered in the Slump Test, that is, when considering this 27% water addition test, this sandy soil has the same fluidity as the rest of the subsequent additions. The same behavior was observed for the CSCE mixtures with clay soil, that is, regardless of the continuous water addition in the mixtures, the constancy of the 145 mm drop height value occurred in the FR of 52%. This shows qualitatively that the FR of 27% for sandy soil is the start of fluidity for the occurrence of CSCE mixtures.

In this same FR of 27%, the Slump Flow test for CSCE mixtures with sandy soil presented a spreading diameter value of 316.67 mm, equivalent to clayey soil with a spreading diameter value of 318.33 mm, in the FR of 52%. So, it is understood that in order to initiate self-compacting in the Slump Flow test, the minimum spreading diameter values suitable for the CSCE mixtures with sandy and clay soil are 316.67 and 318.33 mm, respectively.

The maximum and minimum spreading limits determined for CSCE mixtures with clayey soil were within the FR of 52 to 55%, which is a self-compaction range with proximity to the LL of the clayey soil of 54.86%. This corroborates the assertions of Milani and Silva (2019) about the CSCE system achieving good fluidity without segregation and exudation, which is closely limited by the amount of clay minerals in the soil, that is, by the liquid limit of the soil.

In view of this analysis, regardless of the type of soil, for the application of the Slump Flow test in CSCE mixtures, the ideal range of the spreading diameter from 318.33 to 460 mm should be considered, since this is the common range between the soils, thus guaranteeing the occurrence of the necessary fluidity of the CSCE mixture without segregation and exudation. By convention, in order to help understanding the parameters adopted, they was rounded to the nearest ten, thus, the ideal spreading diameter is between 320 to 460 mm.

Despite the similar rheological behavior of the CSCE admixtures in both flow tests, as represented by the high correlation coefficient values (Figure 5), by applying the Tukey test in the obtained Flow Table test values, both for sandy soil and for clayey soil, no statistical classification was found that would allow creating a reliable range with maximum and minimum spreading limits for this test.

It is believed that the Flow Table is not suitable for evaluating CSCE due to the methodological procedures of the test. According to Roussel, Stefani, and Leroy (2005), the flow stress of conventional cementitious pastes and mortars is higher when compared to a cementitious matrix with plastic consistency, that is, the flow of the mixture is associated with the deformation capacity that the material has and is directly influenced by the amount of water and its surface tension. Similarly, CSCE mixtures in the fresh state have practically zero shear strength; however, when applying the blows established in the flow table, the flow stress of CSCE was altered in a different proportion between the soils, since the deformation of each type of soil is conditioned by the quantities and morphology of its particles. Thus, it was not possible to obtain a direct spreading correlation between the sandy and clayey soils within the flow table test.

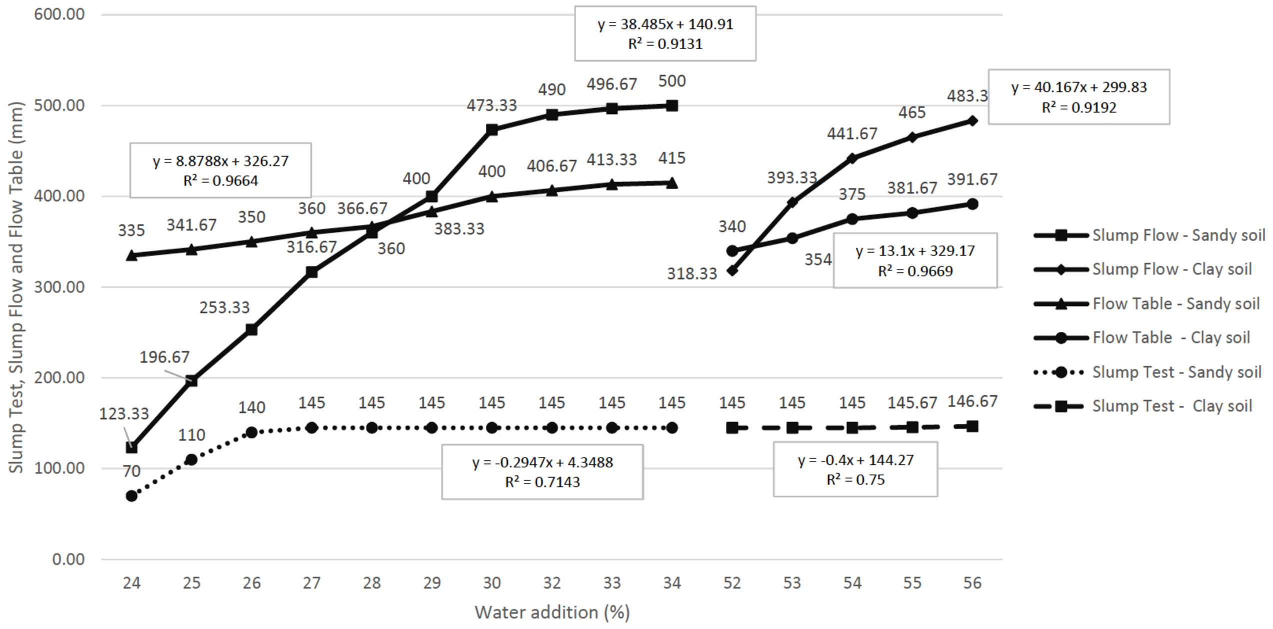


Figure 5. Results of the tests applied on fresh state CSCE mixtures.

In view of these relationships between the experimental tests applied in the fresh state of CSCE admixtures, the Slump Test is not suitable for measuring the flow of CSCE mixtures, however its application in conjunction with the Slump Flow test was important to corroborate the maximum and minimum flow of CSCE mixtures. However, considering the Bingham model to describe the fresh behavior of cement suspensions, the spreading aperture tends to infinity for a viscous fluid without flow stress and, therefore, the Slump Flow with a reduced Abrams cone represented this rheological behavior regardless of the type of soil tested, which can be considered the most appropriate physical test to assess the flow of CSCE mixtures, in addition to being considered simple to perform and effective in obtaining the in situ spread diameter measurement.

Regarding the mechanical test, Table 3 and 4 show the simple compressive strength results of CSCE mixtures with sandy and clay soils. The simple compressive strength values of CSCE mixtures with sandy soil decreased as the incorporated water content increased, with the addition of 27% of water, resulting in a significant decrease in strength, and the remaining water content increases did not cause significant differences in the simple compressive strength values of CSCE mixtures with sandy soil.

This shows the conformity of the proposal for the self-compaction parameter of CSCE mixtures, since by adopting the minimum spreading spread limit of the Flow Table test at 320 mm, it was precisely the point at which the CSCE mixture with sandy soil left the plastic state and started its liquid, that is, in the 24 to 27% FR the CSCE mixtures with sandy soil showed greater cohesion due to its fresh state being on the threshold between plastic and liquid, thus resulting in a significant higher simple compressive strength value when compared to the other CSCE mixtures with sandy soil. For the CSCE mixtures with clay soil, none of the simple compressive strength results showed significant difference, it also corroborates that these mixtures were flow in the fresh state.

The better mechanical behavior of CSCE mixtures with sandy soil than in clayey soil are emphasized in terms of absolute simple compressive strength values. According to Coelho, Santos, and Santos (2007), clays, also called clay minerals, have a lamellar or elongated shape and are considered chemically active. Because the diameter is less than 0.05 mm, they have large specific surface area and high degree of plastic, which complicates the chemical-mechanical stabilization for this type of soil. However, due to the round shape of quartz particles, they interact better with cement and are easier to stabilize, corroborating the behavior presented by the CSCE mixtures with sandy and clayey soils.

Thus, it confirms the greater importance of the cementing agent for the mechanical strength gain of CSCE than the performance of water in the mechanical stabilization process, since, regardless of the type of soil, there were no significant differences between the simple compressive strength values of the CSCE mixtures with increasing water content. It is noteworthy that the gradual water increase has greater influence on the physical behavior of the hardened CSCE system in terms of porosity, permeability and water absorption capacity (Balaji, Mani, & Reddy, 2017).

Conclusion

Tropical soils with predominant particle size composition of clay or sand, where 100% of particles that are smaller than 5 mm, were considered suitable for mixing with water+cement+superplasticiser admixture to obtain stable CSCE. The use of other types and dosages of cementitious material is recommended to improving the physical-mechanical behavior of the CSCE to apply as construction material of monolithic wall.

The soil with a similar proportion between silt and clay particles resulted in an unstable soil and showed physical-mechanical stabilization problems in the presence of water+cement+superplasticiser admixture to reach the self-compaction of the CSCE mixture.

For the dosage study of the cement-stabilised self-compacting earth (CSCE) mixture, the soil liquid limit (LL) parameter is ideal to use as a starting point to determine the optimal water content of the CSCE material. On the other hand, for soils that do not have well-defined liquid limit, the recommendation is to perform the linear shrinkage experimental test of the box, and select the water content within the fluidity range as a starting point; that is, the water range added to the CSCE that was added to the box with the mixture, without the need for compaction or vibration, and after hardening, there were no cracks and fissures and the shrinkage was less than 20 mm.

The experimental tests and the statistical analysis applied to the study CSCE flow showed a good relation between sandy and clayey soils from the Slump Flow, thus demonstrating to be the most suitable test for determining CSCE self-compaction criteria.

To consider the soil+water+cement+superplasticiser mixtures as a self-compacting material, without the occurrence of segregation and exudation in the fresh state, the Slump Flow test is recommended, adapting dimensions the Abrams cone to top diameter = 50 mm, bottom diameter = 100 mm and height = 150 mm; and consider as a flow parameter that the CSCE mixtures have a spreading diameter value of 320 to 460 mm during this test.

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