Soil Mixtures with Additions for Expansive Soil Stabilization: A Systematic Literature Review

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Abstract: The volumetric instability of expansive soils poses a significant challenge to civil engineering, particularly affecting pavement works, foundations, and supporting structures. This behavior, associated with the presence of clay minerals such as montmorillonite, results in considerable variations when changes in moisture content occur, triggering expansion and shrinkage processes that compromise the performance and durability of structures. Traditionally, the stabilization of these soils is carried out using cement or lime, however, such methods may increase the stiffness and brittleness of the material, impairing its performance under dynamic loads. In this context, the use of natural or synthetic fibers emerges as a promising alternative, acting as reinforcement to improve strength and crack control. The analysis of rheological properties is crucial for evaluating the feasibility of applying these mixtures in the field. This study presents a systematic literature review, with data extracted from the Scopus database and analyzed in RStudio using the Bibliometrix package, aiming to map the state of the art regarding stabilizing mixtures for expansive soils. The search was guided by keywords such as "soil-cement," "expansive soil," and "lime," followed by the application of filters for subject area, document type, and source type. A total of 105 articles published between 1999 and 2025 were selected. The bibliometric analysis revealed a significant increase in scientific production since 2018, led by countries such as China, India, and Australia, in addition to the concentration of publications in high-impact journals. The results indicate that the integration of fibers, combined with rheological control, has significant potential to mitigate shrinkage and improve the mechanical performance of expansive soils, providing technical support for the development of more durable and environmentally appropriate solutions in geotechnical engineering.
Keywords: Soil-cement. Expansive soil. Fiber. Shrinkage. Rheology. Lime.

1. Introduction

The volumetric instability of expansive soils represents a significant challenge for civil engineering, especially in paving and foundation works. This behavior is related to the presence of 2:1 clay minerals, such as montmorillonite, which promote significant volume variations when there are changes in moisture content, resulting in expansion and shrinkage processes [1]. In the Brazilian context, among the main known expansive formations are the sedimentary basins of Recôncavo Baiano, Paraná, and Rio Grande do Sul [2].

The shrinkage, present in soil mixtures, is a time-dependent phenomenon that can be defined as the increase in deformation over time, with a reduction in the volume of the concrete element without the action of loads at a constant temperature [3], [4]. These deformations also occur when no moisture transfer is allowed with the external environment, being attributed to chemical reactions and internal structural changes [5]. In this sense, such deformations cause the appearance of surface or global cracks, reducing performance and affecting properties in the hardened state.

Traditionally, the methods for stabilizing expansive clay soils involve the use of binding materials such as cement and lime, which are the most common forms of treatment to improve

their physical and mechanical properties. Although widely used, these treatments can make the soil excessively rigid and brittle, which is unfavorable under dynamic loading conditions, such as those arising from traffic on pavement systems [6].

In view of this, some research has explored more resilient alternatives, among which the use of natural and synthetic fiber reinforcement stands out. The fibers act as reinforcing elements in the soil matrix, promoting a more cohesive internal structure that improves the overall strength and stability of the material. This reinforcement contributes to a more uniform distribution of stresses throughout the soil, minimizing localized deformations and reducing excessive pore pressure during loading [7].

In addition, the rheological behavior of the mixtures must also be considered, as properties such as viscosity and yield stress directly influence the feasibility of applying the material in the field [8]. Rheology is also used to evaluate the effects of deformation and material flow, as there are relationships between stress, deformation, deformation rate, and time [9], [10], [11].

Thus, it is important to study methods for stabilizing expansive soils, such as using soil mixtures with ideal additions that ensure adequate rheology. In addition, such mixtures should not shrink, making it possible to mitigate problems related to cracking, such as through the use of fibers. Understanding the panorama of research already developed in this area is essential for proposing effective solutions. Therefore, this article aims to present, through a systematic review of the literature based on previously established criteria, the current scenario of scientific investigations involving the analysis of stabilizing mixtures applied to expansive soils for the development of future research in the area.

2. Methodology

This systematic review was conducted with the aim of mapping the state of the art related to the use of additions for stabilizing expansive soils, focusing on mitigating the volumetric shrinkage of soil-cement mixtures, especially with the use of fibers, in addition to rheological analysis of this mixture. To this end, a structured approach was adopted based on previously established criteria and consisting of the stages of searching, filtering, and analyzing bibliographic data.

2.1. Tools and Platform

The data collection was performed in the Scopus database, considered one of the most comprehensive for scientific publications in the fields of engineering, geosciences, and materials sciences. The extracted data were analyzed using R Studio software, using the Bibliometrix package, an open-source statistical tool specialized in bibliometric analysis and scientific mapping. Bibliometrix allows the

processing of large volumes of data, extracted from databases such as Scopus and Web of Science, with a high level of analytical detail. In addition, its application offers rigorous and automated support for the generation of metrics and visualizations that reveal patterns, trends, and the structure of knowledge in a given area. Given its robustness and reliability, Bibliometrix was chosen as the main tool for the analysis stage, providing quantitative support for the systematic review developed and thus enabling a qualitative interpretation of these results.

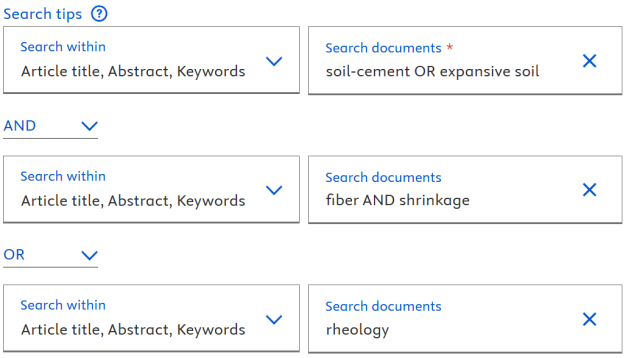
2.2. Search Strategy

The definition of search terms was guided by the main elements addressed in the research, considering the following keywords:

- Soil type and stabilizers: soil-cement, expansive soil, lime;
- Mechanical and physical performance: fiber, shrinkage;
- Application properties: rheology.

Figure 1 shows the main search filter used on the Scopus platform, which combines Boolean operators (AND / OR) to link the different topics of interest. The search field was limited to "Article title, Abstract, Keywords" in order to refine the results to the most relevant publications.

Figure 1. Keywords used to perform data extraction on the Scopus platform.



The combination of terms sought to cover experimental studies related to soil-cement and soil-lime mixtures applied to expansive soils, also considering the impact of fibers on shrinkage and rheological properties. This strategy was designed to capture different stabilization approaches and associated properties, as well as studies that relate performance and applicability in the field.

2.3. Application of Filters

After the initial search, 194 documents were obtained and then additional filters were applied within the Scopus platform itself to further refine the results and ensure the relevance of the studies collected. The inclusion criteria were:

- Subject Area: Engineering, Materials Science, Earth and Planetary Sciences, Environmental Science;
- Document Type: scientific articles only;
- Source Type: scientific journals only;
- Keyword Filter: Shrinkage, Soils, Soil Cement, Expansive Soil(s), Fibers,

Rheology, Lime, Swelling, Soil Stabilization, Cement(s), Soil Reinforcement, Stabilization, Rheological Property, Fiber Reinforced Materials, Fiber Reinforcement, Soil Moisture, Soil-cement.

After applying these filters, the number of documents was reduced to 105 articles, which were exported in .bibtex format, compatible with Bibliometrix. It is worth noting that there were no criteria for excluding articles.

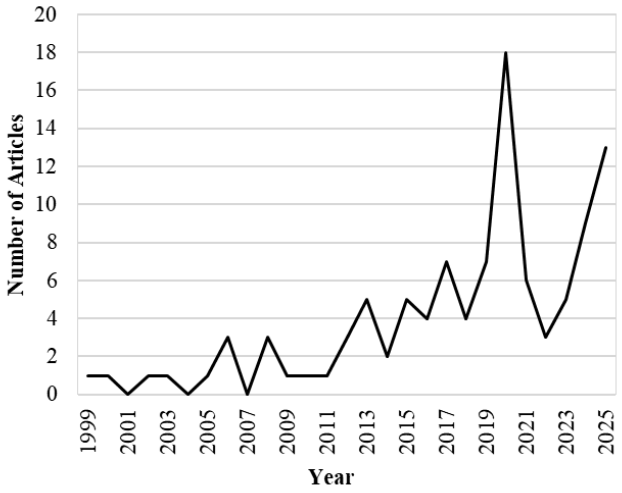
3. Results

The bibliometric analysis of the 105 selected articles, carried out using the Bibliometrix tool, made it possible to identify relevant patterns in scientific production related to the stabilization of expansive soils with additions (soil-cement, lime, fibers) and the study of rheological and shrinkage properties. The tool generated graphs, tables and relevant indicators on scientific production in the area, such as the most productive authors, most frequent keywords, journals with the highest number of publications, etc. These results are presented and discussed in the following section of this article.

3.1. Annual Scientific Production

The database extracted from Scopus covers a period of 26 years, beginning in 1999. In this sense, the period of scientific production analyzed indicates a growth trend over time, with a clearer acceleration since 2018. Although there are annual fluctuations — including a decline observed between 2020 and 2022, probably influenced by the Covid-19 pandemic — the long-term trend is toward an increase in the number of publications, suggesting consolidation and expansion of scientific interest in the topic. This upward trajectory indicates that the area is attracting greater attention, possibly due to the demand for solutions applied to the stabilization of expansive soils and the advancement of experimental and analytical techniques.

Graphic 1. Annual Scientific Production.



3.2. Most Relevant Sources

An analysis of the most relevant sources shows that production is concentrated in specialized journals in the field of study, with emphasis on the source Construction and Building Materials, with eight published documents, followed by the Journal of Materials in Civil Engineering and Yantu Lixue/Rock and Soil Mechanics, with five documents each, also indicating their thematic

importance for the subject. These journals have a high impact factor and are responsible for disseminating a significant portion of the most influential research, which reinforces their role as strategic channels for scientific dissemination. Table 1 provides guidance for future searches, such as choosing journals to submit results to and identifying scientific communities focused on the issues addressed in this article.

Table 1. Most Relevant Sources.

Source	No. of Documents
CONSTRUCTION AND BUILDING MATERIALS	8
JOURNAL OF MATERIALS IN CIVIL ENGINEERING	5
YANTU LIXUE/ROCK AND SOIL MECHANICS	5
CEMENT AND CONCRETE COMPOSITES	4
GEOTECHNICAL AND GEOLOGICAL ENGINEERING	4
JOURNAL OF BUILDING ENGINEERING	4
JOURNAL OF NATURAL DISASTERS	4
MATERIALS	4
GEOMECHANICS AND ENGINEERING	3
INDIAN GEOTECHNICAL JOURNAL	3

3.3. Most Relevant Authors

The analysis of the most relevant authors highlights the existence of researchers with recurring production and consolidated impact in the field, who act as hubs for the dissemination of knowledge. Authors such as WANG Y., XIAO H. and ZHANG J. have a strong influence on the construction of the theoretical body of the references analyzed.

Table 2. Most Relevant Authors.

Author	No. of Documents
WANG Y	6
XIAO H	6
ZHANG J	4
LI Z	3
PUPPALA AJ	3
XIAO G	3
ZHANG D	3
ABBASPOUR M	2
AFLAKI E	2
BALAN K	2

3.4. Corresponding Authors' Countries

Table 3 lists the country corresponding to the author responsible for submitting and corresponding to the paper. This indicator reveals geographical leadership in scientific production, as each article has only one corresponding author, reflecting where research coordination is carried out and where the main groups conducting experimental studies and publications are located. The data show that China leads with 38 articles, followed by India and Australia.

Table 3. Corresponding Authors' Countries

Country	Articles
CHINA	38
INDIA	16
AUSTRALIA	10
USA	5
BRAZIL	4
CANADA	4
IRAN	4
FRANCE	3
KOREA	3

3.5. Countries' Scientific Production

Table 4 considers all articles in which a country appears in the affiliation of at least one author, regardless of whether or not they are the corresponding author. Unlike the previous indicator, the same document can be counted for more than one country, reflecting total participation in publications (including international collaborations and co-authorships), thus providing a broader view. In this scenario, China has a significant presence, with 95 occurrences, followed by India and the United States. Brazil ranks sixth, with seven occurrences. Comparing the two indicators allows us to infer patterns of collaboration: differences in position indicate, for example, countries with a high presence in co-authorships but a lower frequency as the corresponding author's headquarters (and vice versa).

Table 4. Countries' Scientific Production

Country	No. of Documents
CHINA	95
INDIA	35
USA	16
AUSTRALIA	14
FRANCE	8
BRAZIL	7
SOUTH KOREA	6
CANADA	5
IRAN	5

3.6. Most Global Cited Documents

The documents with the highest number of international citations correspond to reference studies that establish conceptual or methodological foundations for the field. Identifying these documents is essential for the research in question, as it will guide the selection of studies to be read and extracted in terms of experimental protocols, mixing parameters, and rheological evaluation methods, thus contributing to the definition of the main lines of investigation.

Table 5. Most Global Cited Documents.

Document	Global Citations
WANG Y, 2017, Int. J. Geomech.	238
KHEDARI J, 2005, Cem. Concr. Compos.	214
CHADUVULA U, 2017, Appl. CLAY Sci.	182
MA G, 2020, Constr. Build. Mater.	158
PUNTHUTAECHA K, 2006, J. Mater. Civ. Eng.	156
KHATTAK MJ, 2006, Int. J. Pavement Eng.	153
PUPPALA AJ, 2000, Transp. Res. Rec.	147
OLGUN M, 2013, Geosynth. Int.	145
LEE S, 2017, Geomech. Eng.	136
SOLTANI A, 2017, Geotech. Geol. Eng.	135

3.7. Most Relevant Words

The mapping highlights the most relevant words within the selected article database. It is important to note that these words are derived from the content of the sample articles and represent the thematic emphasis found in the analyzed literature, not always corresponding exactly to the terms originally used in the Scopus search strategy. However, there is still a clear predominance of terms directly associated with the central concepts of the study, such as “shrinkage”, “soil cement”, “rheology”, “fibers”, “expansive soil” and “lime”, revealing an alignment between the research and the issue investigated.

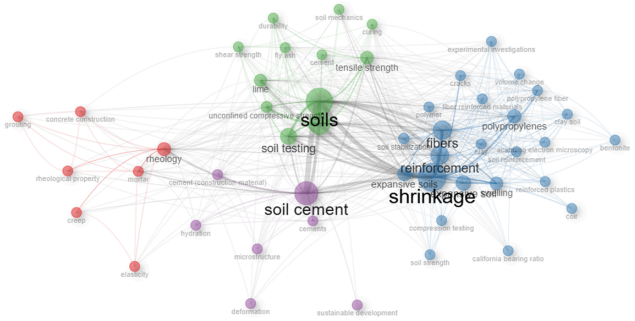
Table 6. Most Relevant Words.

Keyword	Occurrences
shrinkage	55
soils	45
soil cement	40
compressive strength	38
reinforcement	28
rheology	28
fibers	25
soil testing	23
expansive soil	22
lime	21

3.8. Co-occurrence Network

The co-occurrence network reveals the relational structure between terms and allows us to identify subareas and central nodes that link different topics. In the network, we can see the formation of clusters that bring together concepts such as "soil-cement / lime", "fibers / reinforcement", "shrinkage / clay soil" and "rheology / soil mechanics". These clusters help map predominant lines of research and potential conceptual connections for the project's experimental proposal.

Figure 2. Co-occurrence Network.



4. Conclusion

The systematic review carried out made it possible to map the current landscape of research related to the stabilization of expansive soils through mixtures with additions, highlighting the use of soil-cement, lime, and fibers, as well as the relevance of evaluating rheological and shrinkage properties. There has been continuous growth in scientific production in this area, especially since 2018, which shows the increased interest in more effective and sustainable solutions for the treatment of these soils.

The bibliometric analysis identified China, India, and Australia as leaders in scientific production, while high-impact journals, such as Construction and Building Materials, Journal of Materials in Civil Engineering, and Yantu Lixue/Rock and Soil Mechanics, concentrate a large part of the most relevant publications. The most recurrent keywords reinforce the centrality of topics such as "shrinkage", "soil cement", "fibers" and "rheology", and co-occurrence networks confirm the convergence of research on issues that combine mechanical performance, shrinkage control, and field application feasibility.

The results obtained demonstrate that fiber reinforcement has significant potential to mitigate problems of volumetric instability and cracking in expansive soils, especially when associated with careful control of rheological

properties. In this context, this article provides a solid basis for guiding future experimental studies, assisting in the choice of materials, methodologies and analysis parameters that can contribute to the development of more durable and environmentally appropriate solutions in geotechnical engineering.

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