REVISTA DE GEOCIÊNCIAS DO NORDESTE

Northeast Geosciences Journal

ISSN: 2447-3359

v. 11, nº 2 (2025)

https://doi.org/10.21680/2447-3359.2025v11n2ID40186

Influence of adding a salt production by-product (Carago) and curing time on the swelling potential of an expansive soil from the city of Mossoró in the state of Rio Grande do Norte (RN)

Influência da adição de um subproduto da produção de sal (Carago) e do tempo de cura nas propriedades de expansibilidade de um solo expansivo da cidade de Mossoró no estado do Rio Grande do Norte (RN)

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Abstract: Expansive soils have as their main characteristic the volumetric variation due to the change in moisture content that results in damage to engineering works. The stabilization of these soils can be done with the addition of binders that reduce or eliminate the expansion. This research aimed to evaluate the influence of the addition of carago on the properties of expansibility and shear strength of an expansive soil in the city of Mossoró/RN. For this, tests of geotechnical characterization, compaction, free expansion, expansion stress and direct shear strength were carried out in soil mixtures with addition of 5% and 10% of carago. The samples with 10% carago showed a reduction in free expansion, with emphasis on the 25% reduction in the samples with 7 days of wet curing. An increase in the expansion stress occurred in all samples with carago subjected to dry curing, with the exception of the sample with 10% carago and without curing. Longer dry curing time increased free expansion and expansion stress in all samples.

Keywords: Expansive soil; Stabilization; Gypsum.

Resumo: Os solos expansivos têm como principal característica a variação volumétrica a partir da mudança do teor de umidade que resultam em danos nas obras de engenharia. A estabilização desses solos pode ser feita com a da adição de aglomerantes que reduzam ou eliminem a expansão. Essa pesquisa teve como objetivo de avaliar a influência da adição de carago nas propriedades de expansibilidade e resistência ao cisalhamento de um solo expansivo da cidade de Mossoró/RN. Para isso, foram realizados ensaios de caracterização geotécnica, compactação, expansão livre, tensão de expansão e resistência ao cisalhamento direto em misturas de solo com adição de 5% e 10% de carago. As amostras com 10% de carago apresentaram redução da expansão livre, com destaque para a redução de 25% nas amostras com 7 dias de cura úmida. Ocorreu aumento na tensão de expansão em todas as amostras com carago submetidas à cura seca, com exceção da amostra com 10% de carago e sem cura. O maior tempo de cura seca elevou a expansão livre e a tensão de expansão em todas as amostras.

Palavras-chave: Solo expansivo; Estabilização; Gipsita.

Received: 13/05/2025; Accepted: 22/10/2025; Published: 18/12/2025.

1. Introduction

The volumetric variation of a soil is influenced by intrinsic factors, such as mineralogy, texture, and structure, as well as external factors, such as climate, vegetation, and fluctuations in the water table (FERREIRA et al., 2017). The combination of these two groups of factors leads to changes in moisture content and, consequently, to variations in suction. When suction increases, the soil contracts; when suction decreases, the soil swells (MEDEIROS et al., 2023).

Soil swelling and contraction can lead to structural damage in engineering works, highlighting the need for stabilization. Stabilization may be physical or chemical. Physical stabilization includes compaction, pre-wetting, and electrokinetic treatment, whereas chemical stabilization is carried out by adding materials such as cement, lime, and fly ash, aiming to alter the soil's chemical matrix and ensuring greater stability and strength (BARMAN & DASH, 2022).

Despite being the most widely used stabilizing agents for expansive soils, the production of cement and lime entails burning processes that release considerable quantities of greenhouse gases. Moreover, these gases are responsible for current climate change. Due to this, there is an urgent need to investigate other materials and waste products that generate less environmental impact while providing similar effectiveness in stabilizing expansive soils.

Research on using waste and alternative materials in engineering works has become increasingly widespread. In earthworks, identifying low-impact, environmentally sustainable materials is crucial, as these projects require substantial material volumes. One such material is gypsum or recycled plaster. According to Abdolvand and Sadeghiamirshahidi (2024), gypsum can significantly improve the unconfined compressive strength and California Bearing Ratio (CBR) of soils, especially expansive and highly plastic clays, although the results vary depending on the origin of the gypsum or recycled plaster.

In this context, a waste product generated by the salt industry, popularly known as *carago,* has shown promising potential for geotechnical applications. This waste comprises calcium sulfate dihydrate (CaSO4.2H2O), the same chemical composition as gypsum. For many years, *carago* was used only as fill material, deposited in riverbeds and streams, or accumulated in salt plant yards, occupying areas intended for salt storage. Its first practical use was as a primary surface layer for rural roads and urban streets in salt-producing towns. As a result of this application, *carago* became popularly known as "white asphalt." More recently, it has been sold to cement factories in the Mossoró/RN region (GOMES FILHO, 2019).

In current studies, pure *carago* has shown a CBR of 78.9% and a volumetric change of 0.02% under Modified Proctor compaction energy, which classifies the material as having potential for use as a base layer in roads with moderate traffic. It also demonstrated increasing unconfined compressive strength with longer curing times (SOUZA, 2024).

Thus, this study aimed to assess the influence of *carago* addition, as well as curing time and curing type, on the swelling potential of an expansive soil from the city of Mossoró/RN.

2. Methodology

Figure 1 illustrates the stages of the study and the procedures undertaken at each stage, aimed at characterizing the materials and obtaining the data required for the analysis.

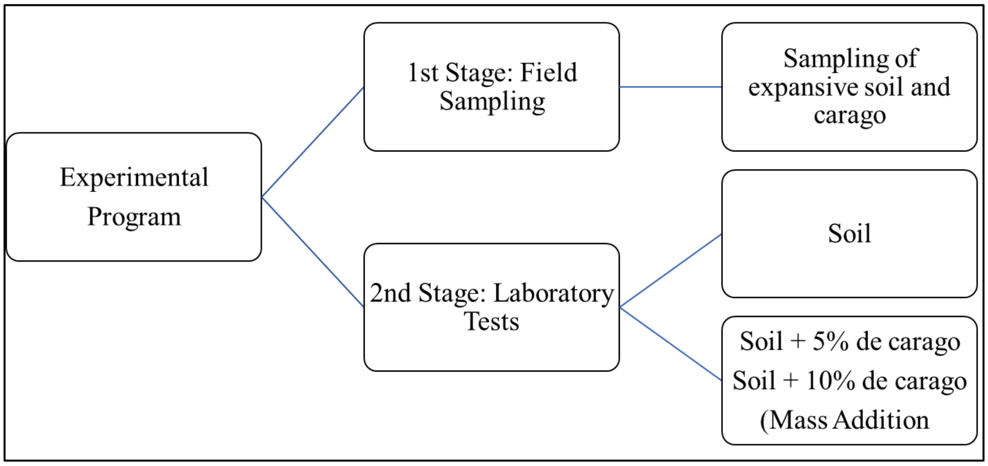


Figure 1 – Experimental program for the study.
Source: Authors (2025).

2.1 Materials Collection

In the first stage, the materials were collected, and their coordinates are shown in Figure 2. The soil was collected at P1, and P2 corresponds to the location of the salt plant that provided the *carago*.

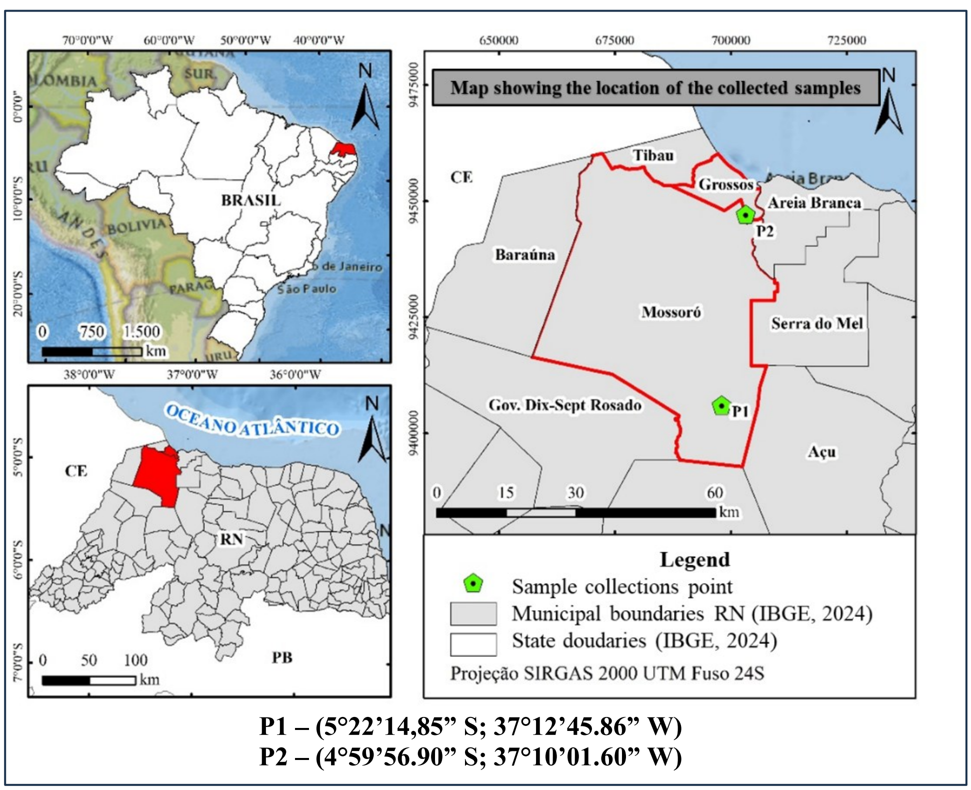


Figure 2 – Map showing the location of the collected samples.
Source: Authors (2025).

The site chosen for collecting the expansive soil sample was selected based on Santos (2017), who identified a soil with a pedological classification of Chernosol/Vertisol as having an "Extremely High" swelling potential, according to the classification proposed by Yukselen-Aksoy and Kaya (2010).

Figure 3 shows that the soil is grayish and has organic matter, gravel, and some surface cracks. It should be mentioned that the sample was challenging to collect due to the material's high resistance in the field.

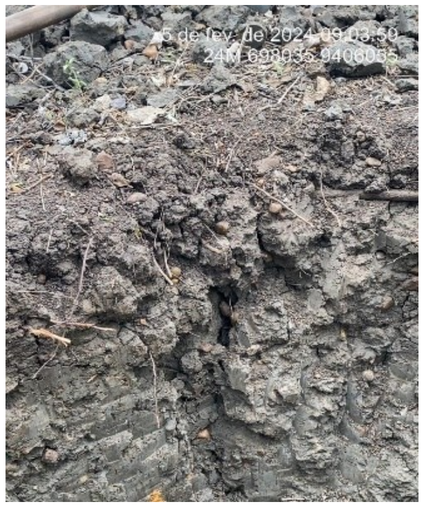


Figure 3 – Expansive soil profile of the Mossoró/RN region.
Source: Braz (2024).

The *carago* was provided by a salt plant in the city of Grossos/RN, already packaged in raffia sacks of approximately 30 kg each. However, after harvesting, the material is usually stored and left exposed outdoors in the salt plant yards to reduce moisture content. The raw *carago* is light gray and contains many clods, resembling coarse sand with gravel. This differs from the material used by Araújo (2023), as the *carago* was white, it had a fine particle size based on tactile–visual analysis, and well-defined crystals.

Once the material was received in the laboratory, it was kept in its original packaging until test preparation. The *carago* was manually disaggregated, and the portion sifted through the No. 40 (0.42 mm) sieve was selected for use, as shown in Figure 4.

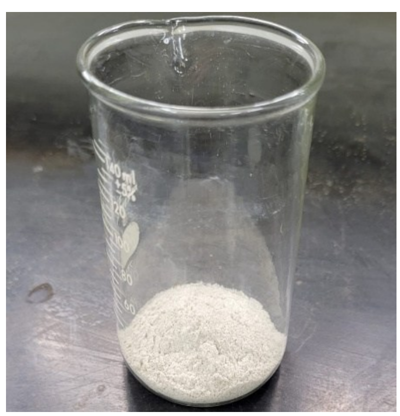


Figure 4 – Disaggregated carago, sifted through the No. 40 sieve.
Source: Authors (2025).

2.2 Methods

In Stage 2, the materials were prepared in accordance with NBR 6457 (ABNT, 2016). After preparation, the soil and the mixtures were subjected to the tests listed in Table 1, carried out at the Soil Mechanics Laboratory at the Federal University of Rio Grande do Norte (UFRN).

Table 1 – Laboratory tests performed on the pure soil and mixtures.

Test	Standard	Materials
Grain Size Distribution	NBR 7181/2016	Soil
Liquid Limit	NBR 6459/2016	Soil
Plastic Limit	NBR 7180/2016	Soil
Specific Gravity of Solids	DNER-ME 093/94	Soil and soil–carago
Soil Compaction	NBR 7182/2016	Soil and soil–carago
Free Swell	ASTM D4546-21	Soil and soil–carago
Swell Stress	ASTM D4546-21	Soil and soil–carago

Source: Authors (2025).

The specimens used for the free swell and swell stress tests were labeled as DCS (Dry-Cured Specimens) for those subjected to dry curing, and WCS (Wet-Cured Specimens) for those subjected to wet curing.

2.2.1 Specimen Molding

The mixtures were prepared using the soil fraction sifted through the No. 4 (4.8 mm) sieve, in accordance with NBR 7182/2016, and the *carago* fraction sifted through the No. 40 (0.42 mm) sieve, to ensure better homogenization. For the Free Swell and Swell Stress tests, the specimens were molded for their respective procedures. Molding was carried out using a semi-static process using a press, as shown in Figure 5.

Figure 5 – Molding of the test specimens.
Source: Authors (2025).

To determine the mass of materials required, the maximum dry density (ρ_{dmax}) and optimum moisture content (w_{op}) parameters were used, as recommended by Abdolvand and Sadeghiamirshahidi (2024). They were obtained from the Standard Proctor compaction test for each sample. After each molding procedure, the mass, average diameter, and average height were measured, and material was collected to determine the moisture content.

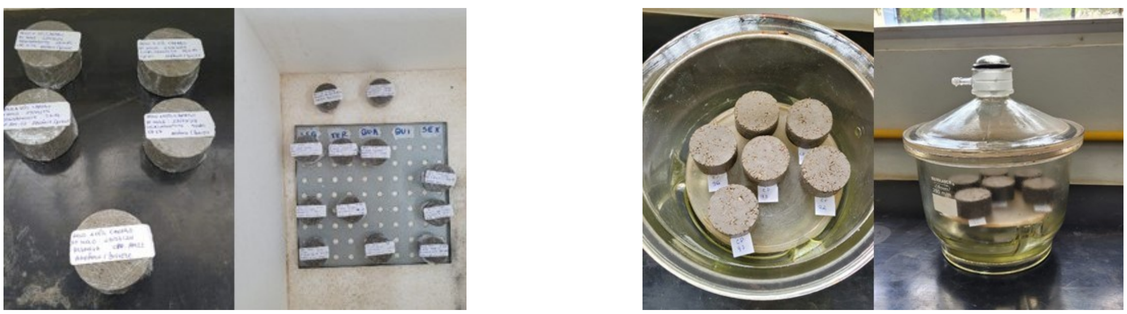
The specimens were molded in different dimensions depending on the curing time to which they were subjected. For the tests in which curing was not required, the specimens were molded in two layers of equal height directly inside the consolidation ring, with approximate dimensions of 50 mm × 20 mm, and then placed into the consolidation cell.

Specimens subjected to curing periods of 7 and 28 days were molded in larger dimensions and later trimmed to fit the consolidation ring at the time of testing. This procedure was essential because the tests and molding processes were carried out simultaneously, and the ring was already in use during testing. The mold used was a cylindrical metal ring measuring approximately 59 mm × 32 mm, and the material was compacted in three layers of equal height.

2.2.2 Test specimen curing

In the dry curing, the test specimens were wrapped in a double layer of plastic film, labeled, and stored in a Styrofoam box, as shown in Figure 8. The aim was to prevent the specimens from losing moisture too quickly.

In the wet curing, the test specimens were stored in an airtight two-level desiccator with free moisture circulation between them. The lower level was filled with distilled water, and the upper level held the specimens, as shown in Figure 6. The aim was to allow free moisture exchange between the enclosed environment and the specimens.



a) *b)*

Figure 6 – a) Test specimens subjected to dry curing. b) Test specimens subjected to wet curing.
Source: Authors (2025).

2.2.3 Free Swell Test and Swell Stress Test

The Free Swell and Swell Stress tests were carried out in accordance with ASTM 4546-21 – Standard Test Methods for One-Dimensional Swell or Collapse of Soils. The standard presents three different methods for conducting the test. However, it should be mentioned that Method A was used for this study. In this method, at least four test specimens with a minimum diameter of 50 mm and a minimum height of 20 mm are required. They must be molded under identical conditions and subjected to different loads to simulate field stresses. Due to equipment limitations, the minimum applied stress was 7 kPa, differing from the 1 kPa recommended by the standard.

After molding, the specimens are placed in the consolidation cell, laterally confined by a metal ring, and positioned in the consolidation press. A seating load of 7 kPa is then applied for at least 5 minutes. If the specimen is being tested for free swell, where the test is conducted under a stress of 7 kPa, it is inundated and readings begin immediately. For the other stress levels, after applying the seating load, an additional load is applied until the desired stress is reached. The consolidation cell is then inundated, and readings are taken with the extensometer at the following time intervals: 0.5 min, 1 min, 2 min, 4 min, 8 min, 15 min, 30 min, 1 h, 2 h, 4 h, 8 h, and 24 h.

3. Results and Discussion

3.1 Geotechnical Characterization Tests

- Grain Size Analysis and Atterberg Limits

The grain size distribution curve of the soil studied is presented in Figure 7, where the predominance of fine fractions can be observed.

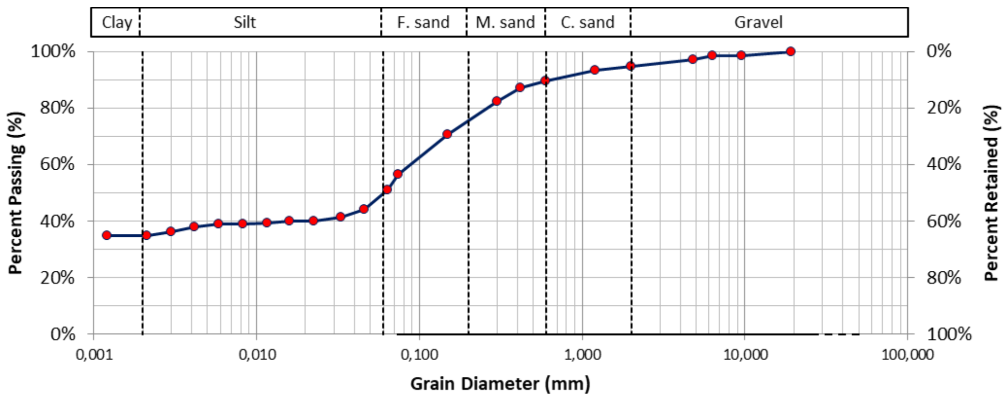


Figure 7 – Rain size distribution curve of the soil investigated.
Source: Authors (2025).

Table 2 presents the details of the grain size distribution curve and the data for Liquid Limit (LL), Plastic Limit (PL), and Plasticity Index (PI).

Table 2 – Details of the grain size distribution curve and Atterberg limits.

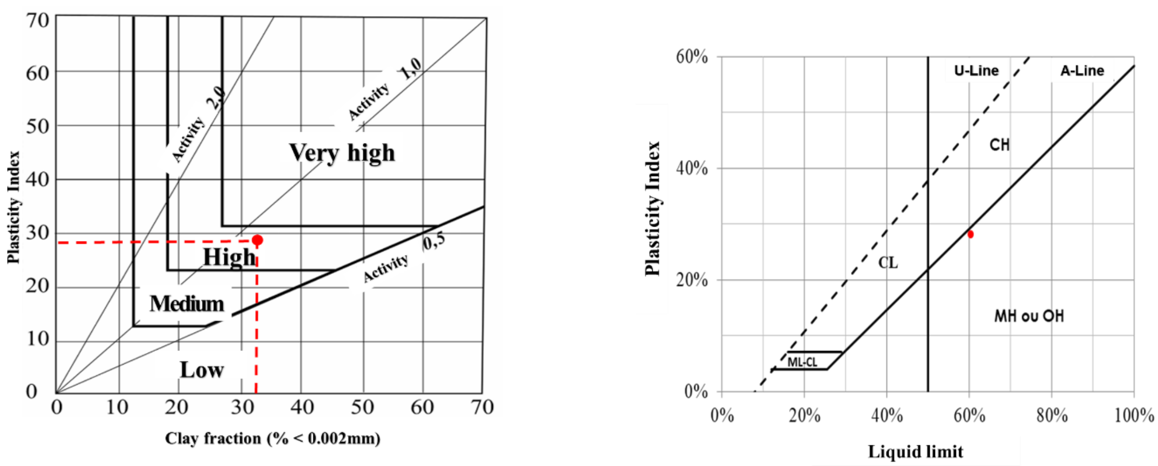
Gravel (%)	Coarse sand (%)	Medium sand (%)	Fine sand (%)	Silt (%)	Clay (%)
5.3	**5.1**	**15.2**	**25.0**	**14.7**	**34.7**
D_{10} (mm)	**D_{30} (mm)**	**D_{60} (mm)**	**LL (%)**	**PL (%)**	**PI (%)**
-	**-**	**0.084**	**60.0**	**31.0**	**29.0**

Source: Authors (2025).

Based on the grain size distribution curve and the Atterberg limits, the soil's swelling potential was assessed indirectly. According to Skempton's (1953) indirect criterion, the clay activity (A), obtained from the ratio between PI and the clay percentage in the soil, is 0.84, which corresponds to a clay of medium activity, similar to Illite. Using Van Der Merwe's (1962) chart, considering the clay fraction of 34.7% and PI = 29%, the clay in this soil is classified as highly active, as represented by point S in Figure 8.

In line with the classifications above, based on the material's workability in the laboratory, certain expansive soil characteristics were already noticeable. The soil contained many clods, requiring two to three cycles of breaking up and drying. Due to its plasticity, the soil could not be disaggregated while the moisture content was still high. As the soil dried, greater energy was required for disaggregation.

During the combined grain size analysis, it was observed that in the sedimentation stage, even using a deflocculant and dispersant, the soil still showed aggregated particles that adhered to the walls of the dispersing cup. In the following stage, to carry out the fine sieving, the soil had to be washed in the No. 200 sieve for approximately 30 minutes, as the clay fraction adhered to and obstructed the sieve mesh, making the test more difficult to perform.



a) *b)*

Figure 8 – a) Location of point S on Van Der Merwe's Chart (1962). b) Soil classification according to the Plasticity Chart.
Source: Authors (2025).

Based on the Liquid Limit of 60.0% and the Plasticity Index of 29.0%, the soil's position on the plasticity chart lies slightly below the "A" line, which classifies it as MH (high-plasticity silt), according to the Unified Soil Classification System (USCS). This can be observed in Figure 15. However, due to the proportions of silt and clay and its proximity to the "A" line, the appropriate classification is MH–CH (high-plasticity clayey silt).

Therefore, according to the indirect swelling classifications, the grain size distribution, and the XRD results reported by Braz (2024), the soil can be characterized as having a high swelling potential.

- Specific Gravity of Solids

The Specific Gravity of Solids (ρ_s) tests were carried out on the soil and the mixtures, and the results are presented in Table 3.

Table 3 – Results of the Specific Gravity of Solids test for the soil and mixtures.

Mixture	ρ_s - (g/cm³)
Pure soil	**2.70**
Soil + 5% carago	**2.64**
Soil + 10% carago	**2.61**

Source: *Authors (2025).*

It can be observed that as the percentage of carago increased, the specific gravity of the solids decreased. This result was expected, as the ρs of carago is around 2.30 g/cm³, according to Souza (2024).

3.2 Compaction Tests

The compaction tests were carried out with reuse and under Standard Proctor energy. The compaction curves of the soil and mixtures are shown in Figure 9.

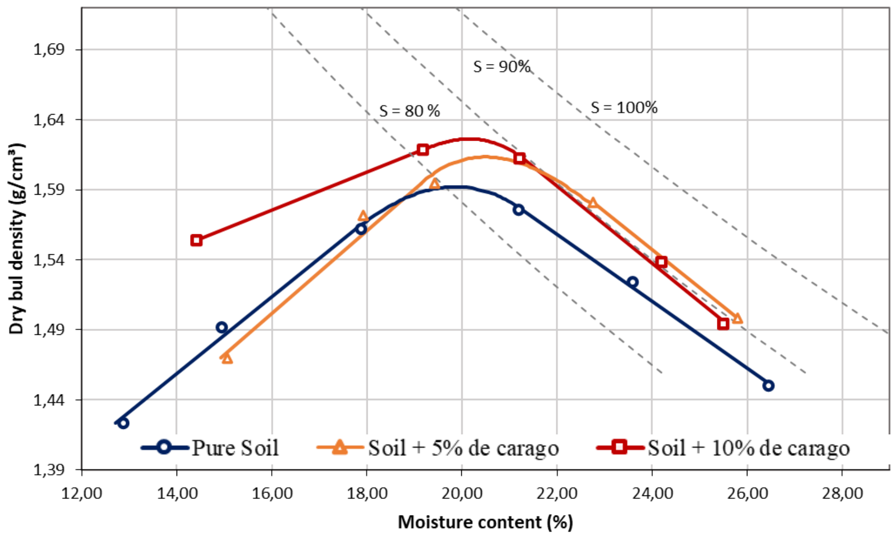


Figure 9 – Compaction curves of the soil and mixtures, performed under standard energy.
Source: Authors (2025).

It should be noted that disaggregating the soil and mixtures after each compaction stage was challenging: specimens with low moisture exhibited high mechanical strength, while higher moisture content resulted in increased plasticity. This behavior is due to the expansive characteristics of the soil and even to inherent properties of *carago* when compacted, as mentioned by Souza (2024).

It can be observed that the maximum dry unit weight ($\rho_{d,max}$) increased after adding *carago*, while the optimum moisture content ($w_{optimum}$) showed only a small variation. Table 4 presents the detailed data from the compaction test.

Table 4 – Influence of adding carago on the compaction parameters.

Mixture	$\rho_{d,máx}$ (g/cm³)	$w_{ótima}$ (%)	e	n (%)
Pure soil	1.59	19.86	0.70	41.2
Soil + 5% *carago*	1.61	20.49	0.64	39.0
Soil + 10% *carago*	1.63	20.17	0.60	37.5

Source: Authors (2025).

A tendency can be observed for the maximum dry unit weight to increase and for the void ratio and porosity to decrease as the percentage of *carago* in the mixture increases. This behavior is consistent with the conclusions drawn by Abdolvand and Sadeghiamirshahidi (2024). As a finer *carago* particle size was used in the mixtures, it was expected that it would occupy more of the soil voids, and as the amount of *carago* in the mixture increased, more voids were filled, resulting in the data presented above.

3.3 Free Swell and Swell Stress

3.3.1 Influence of the percentage of *carago* on the mixture

Figure 10 shows the swelling and contraction exhibited by each test specimen (TS) subjected to the test without a curing process.

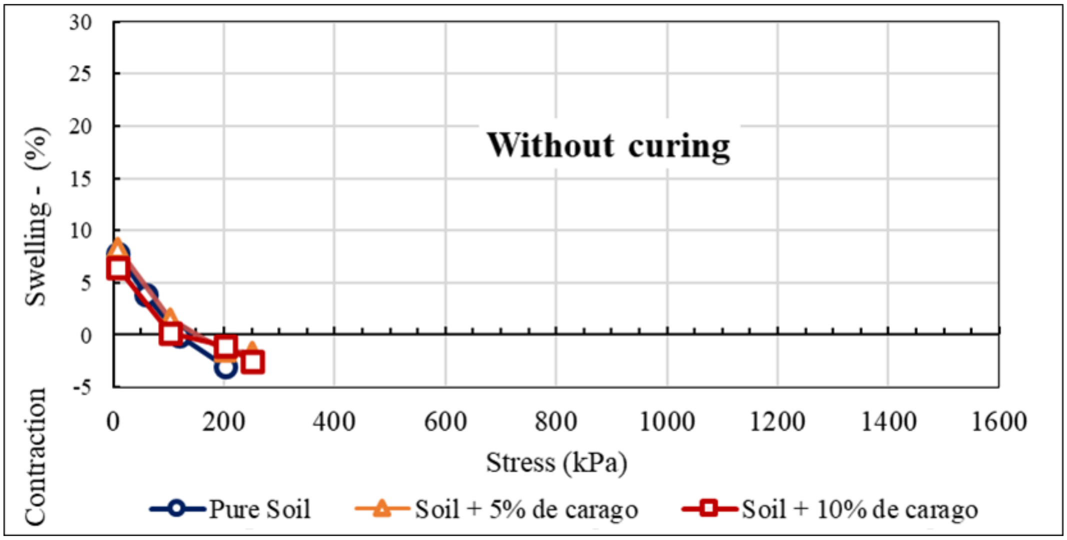


Figure 10 – Swelling and contraction of the specimens without curing.
Source: Authors (2025).

It can be observed that the free swell at 7 kPa ranged between 5% and 10%, with the lowest swell obtained in the sample containing 10% *carago*. The swell stress varied between 120 kPa and 200 kPa. Table 5 shows details of the free swell (FS) and swell stress (SS) results for each sample, as well as their respective variations (*ΔEL*) and (*ΔTE*), in relation to the pure soil sample.

Table 5 – Free Swell and Swell Stress of the samples at zero-day age.

Mixture	Free Swell (%)	*ΔEL* (%)	Swell Stress (kPa)	*ΔTE* (kPa)
Pure soil	**7.8**	**-**	**120**	**-**
Soil + 5% *carago*	**8.3**	**+0.5**	**150**	**+ 30**
Soil + 10% *carago*	**6.6**	**-1.4**	**120**	**0**

Source: Authors (2025).

Based on the data, it is worth mentioning the reduction in free swell in the sample with 10% *carago*, from 7.8% to 6.6%, and the increase in free swell and swell stress in the sample with 5% *carago*, from 7.8% to 8.3% and from 120 kPa to 150 kPa, respectively. Contrary to expectations, only the sample with 10% *carago* showed a reduction in free swell and swell stress. Figure 11 shows the swelling and compression results for each specimen that underwent dry curing for 7 days.

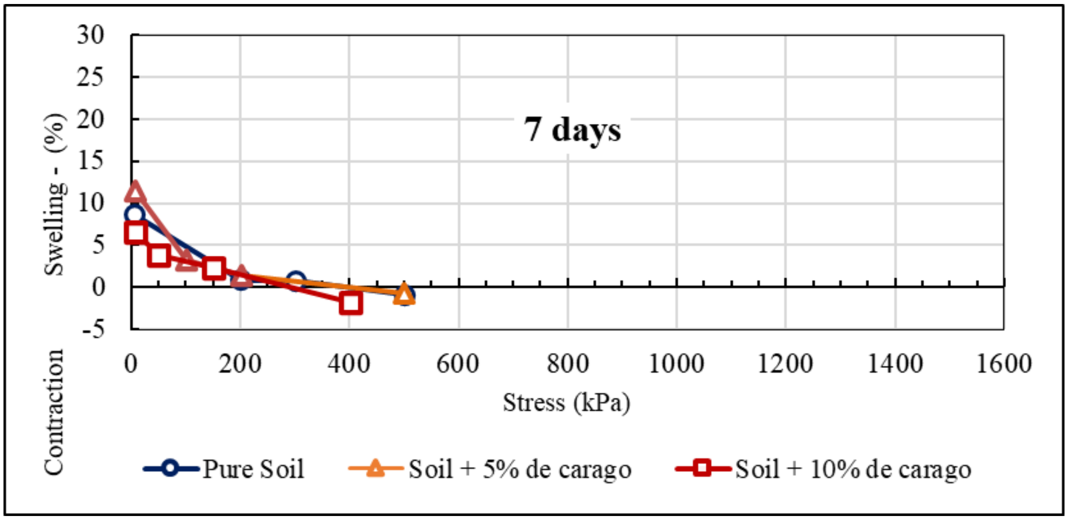


Figure 11 – Swelling and compression of the specimens after 7 days of dry curing
Source: Authors (2025).

It can be observed that the free swell at 7 kPa for the specimens with 7 days of curing ranged between 5% and 15%, with the lowest swell obtained in the sample containing 10% *carago*. The swell stress ranged between 250 kPa and 400 kPa, and the lowest value was also observed in the 10% *carago* sample. Figure 12 shows the swelling and compression results for each specimen that underwent dry curing for 28 days.

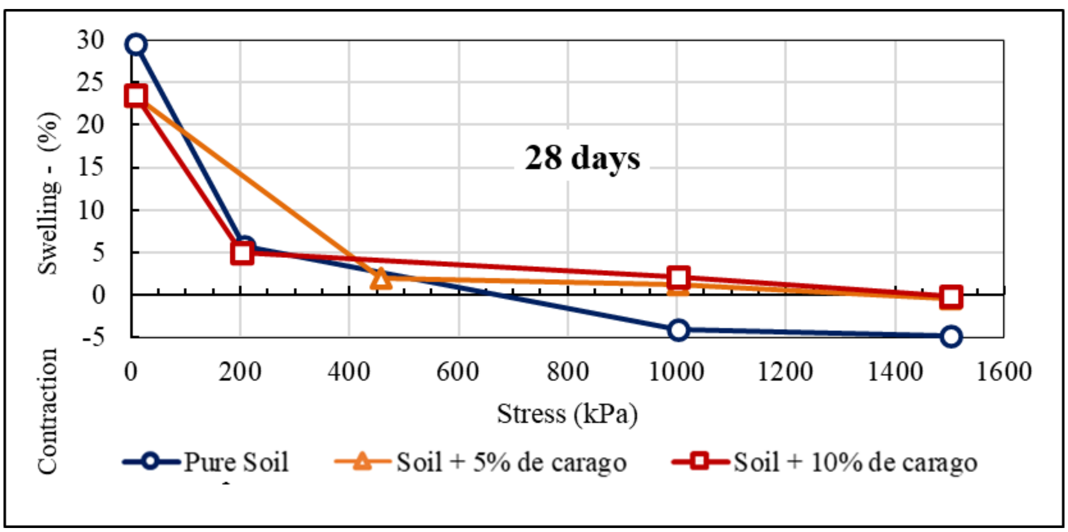


Figure 12 – Swelling and compression of the specimens after 28 days of dry curing.
Source: Authors (2025).

Table 6 – Free Swell and Swell Stress of the samples aged 7 and 28 days, subjected to dry curing.

Mixture	Age (days)	Free swell (%)	*ΔEL* (%)	Swell Stress (kPa)	*ΔTE* (kPa)
Pure soil	**7**	**8.6**	**-**	**385.0**	**-**
Soil + 5% *carago*	**7**	**11.4**	**+2.8**	**385.0**	**0**
Soil + 10% *carago*	**7**	**6.6**	**-2.0**	**290.0**	**-95**
Pure soil	**28**	**29.5**	**-**	**650.0**	**-**
Soil + 5% *carago*	**28**	**23.4**	**-6.1**	**1500**	**+850**
Soil + 10% *carago*	**28**	**23.6**	**-5.9**	**1500**	**+850**

Source: Authors (2025).

At 28 days of dry curing, the free swell ranged between 20% and 30%. In this case, the two samples containing *carago* showed similar free swell values. However, these same samples exhibited high swell stress, exceeding 1 MPa, while the sample with pure soil showed a value close to 650 kPa. In other words, adding *carago* increased the swell stress over 28 days of dry curing. Table 6 shows the results obtained for the samples subjected to dry curing for 7 and 28 days, as well as their respective variations compared to the pure soil sample.

Based on the data, a reduction in free swell and swell stress can be highlighted for the samples containing 10% *carago* after 7 days of curing. During the same period, the samples with 5% *carago* maintained the trend of increasing the free swell, as did the samples without curing. For specimens with *carago* subjected to 28 days of dry curing, there was a reduction in free swell and a 130% increase in swell stress compared to the pure soil specimens. This behavior was unexpected, as a reduction in free swell would typically be associated with a corresponding decrease in swell stress.

Figures 13 and 14 show the swelling and compression results for each specimen subjected to wet curing at ages of 7 and 28 days, respectively.

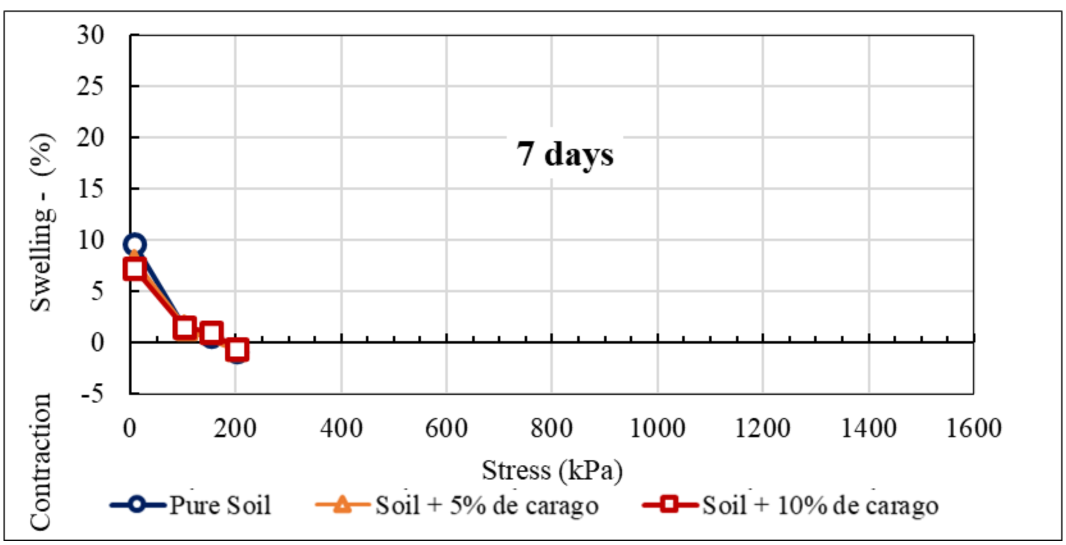


Figure 13 – Swelling and compression of the specimens subjected to 7 days of wet curing.
Source: Authors (2025).

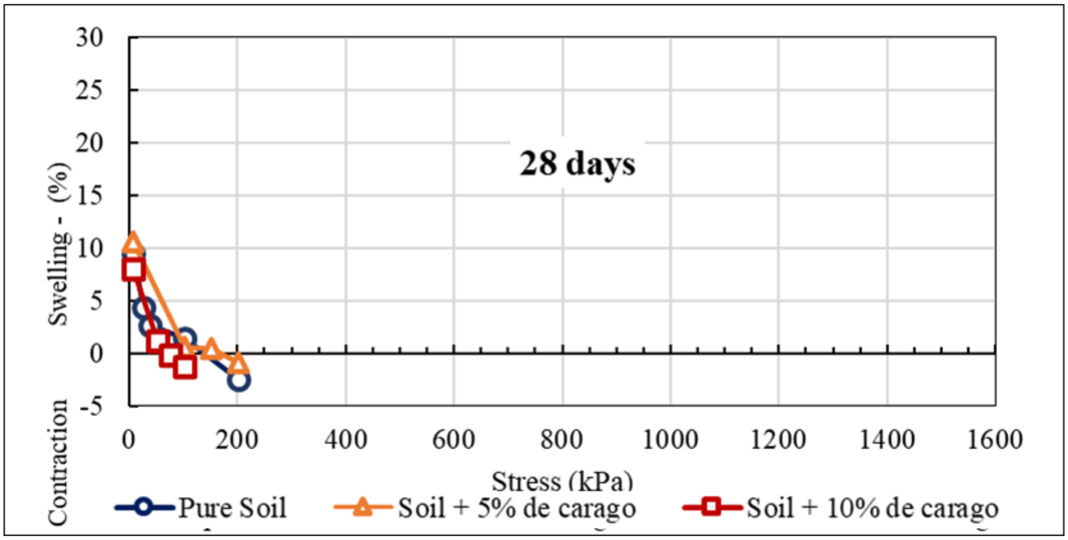


Figure 14 – Expansions and compressions of the specimens subjected to wet curing for 28 days
Source: Authors (2025).

Based on the results, a 25% reduction in free swell can be highlighted for the samples containing 10% *carago* after 7 days of wet curing, and a 15% reduction for those cured for 28 days. The other results did not follow a clear pattern in relation to the percentage of *carago* added.

Under wet curing, the free swell ranged between 5% and 10% for the specimens aged 7 days, and between 5% and 15% for the samples aged 28 days. A reduction in free swell can be noted in the samples with 10% *carago* at both curing ages investigated. Moreover, after 7 days of curing, the samples showed similar swell stress values, ranging from 150 kPa to 200 kPa. For 28 days of curing, a reduction in the swell stress was observed in the specimens containing 10% *carago*.

Table 7 presents data on the free swell and swell stress.

Table 7 – Free Swell and Swell Stress of the samples aged 7 and 28 days, subjected to wet curing.

Mixture	Age (days)	Free Swell (%)	*ΔEL* (%)	Swell Stress (kPa)	*ΔTE* (kPa)
Pure soil	**7**	**9.7**	**-**	**170.0**	**-**
Soil + 5% *carago*	**7**	**8.0**	**-1.7**	**165.0**	**-5**
Soil + 10% *carago*	**7**	**7.2**	**-2.5**	**185.0**	**+15**
Pure soil	**28**	**9.5**	**-**	**140**	**-**
Soil + 5% *carago*	**28**	**10.6**	**+1.1**	**170.0**	**+50**
Soil + 10% *carago*	**28**	**8.0**	**-1.5**	**75.0**	**-45**

Source: Authors (2025).

3.3.2 Influence of Curing Time

Figures 15 and 16 compare the free swell and swell stress, respectively, for the pure soil samples.

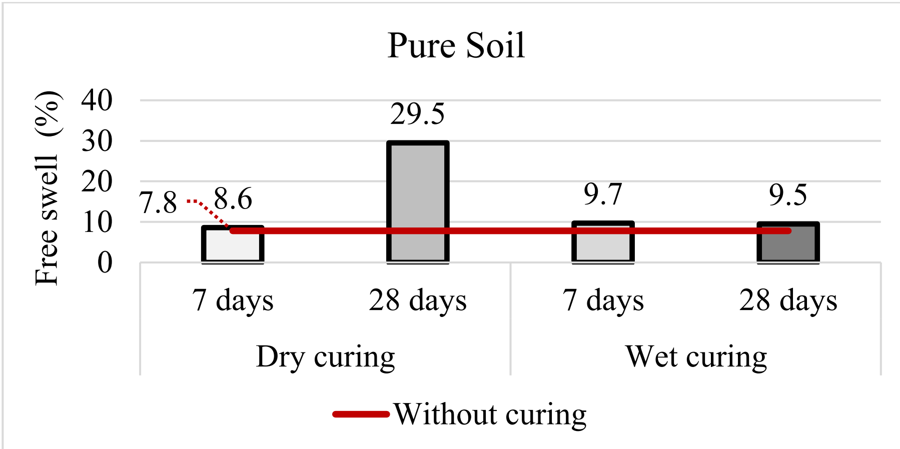


Figure 15 – Comparison of free swell among the pure soil samples without curing and with 7 and 28 days of curing. Source: Authors (2025).

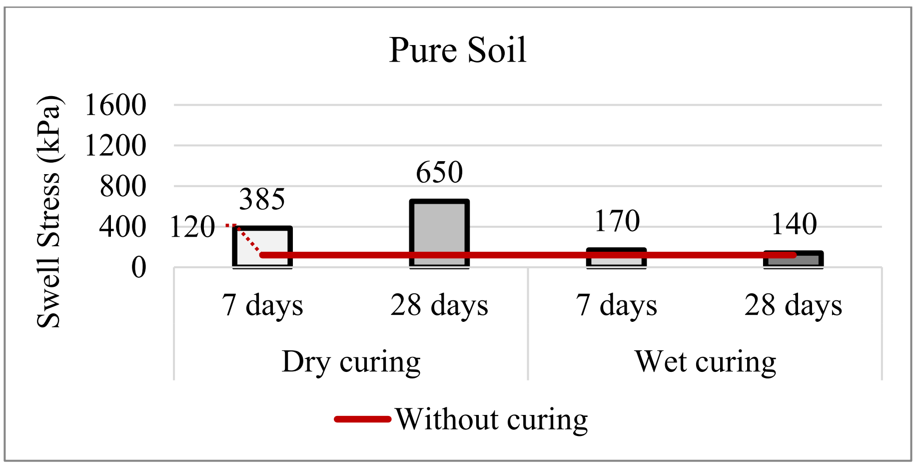


Figure 16 – Comparison of Swell Stress among the pure soil samples without curing and at 7 and 28 days of curing. Source: Authors (2025).

An increase in both the swell stress and free swell can again be observed in the pure soil samples after 28 days of dry curing, with +278% in free swell and +441% in swell stress. Under wet curing, these two parameters showed significantly smaller variations, with an approximate 24% increase in free swell and a 41% increase in swell stress for the 7-day samples. Under the same curing conditions, the 28-day sample showed a 21% increase in free swell.

Figures 17 and 18 present the comparison of free swell and swell stress, respectively, for the samples containing 5% *carago*.

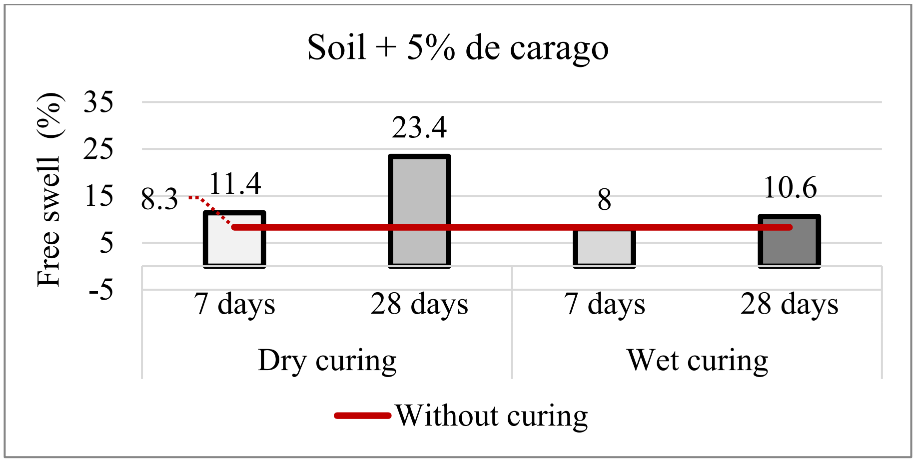


Figure 17 – Comparison of Free Swell among the samples with 5% carago with no curing and at 7 and 28 days of curing.
Source: Authors (2025).

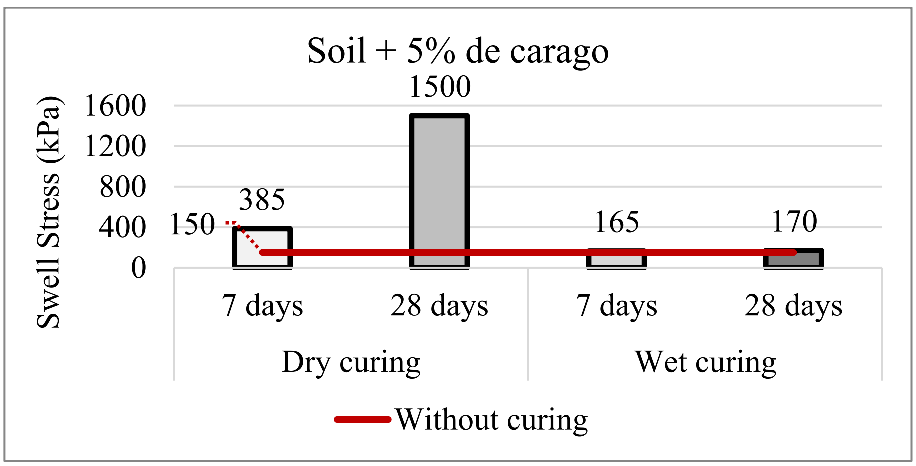


Figure 18 – Comparison of Swell Stress among the samples with 5% carago with no curing and at 7 and 28 days of curing.
Source: Authors (2025).

It can be observed that the trend of increased free swell in the samples after 28 days of dry curing continues, even after adding *carago*. Under this type of curing, the samples showed +27% and +181% in free swell for the 7-day and 28-day samples, respectively. Under wet curing, there was a slight reduction of 3.6% at 7 days and an increase of 27% at 28 days.

This trend of increased free swell under dry curing is attributed to the reduction in moisture content of the samples, which did not occur under wet curing.

The swell stress behavior is identical to that of free swell, with a greater increase under dry curing than under wet curing. An increase of 156% was observed at 7 days and 900% at 28 days. Under wet curing, a similar trend occurred, although the variations were smaller, with increases of 10% and 13% at 7 days and 28 days, respectively.

Figures 19 and 20 compare the free swell and swell stress, respectively, for the samples containing 10% carago.

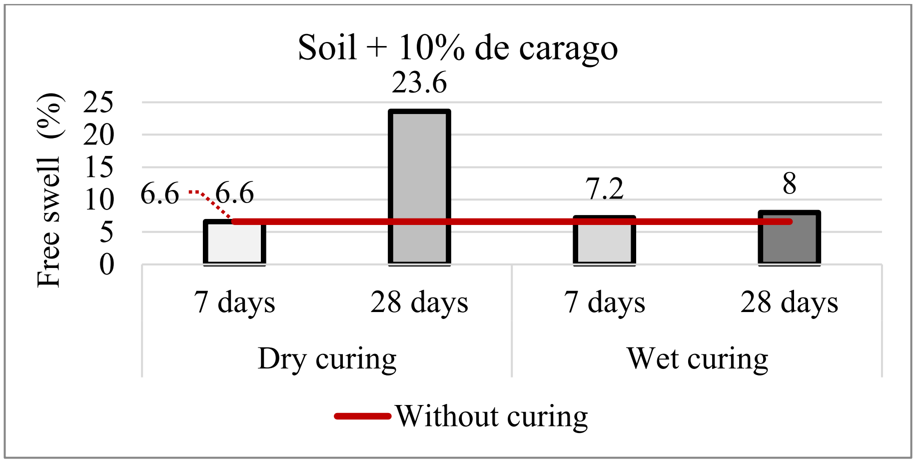


Figure 19 – Comparison of Free Swell among the samples with 10% carago with no curing and with 7 and 28 days of curing.
Source: Authors (2025).

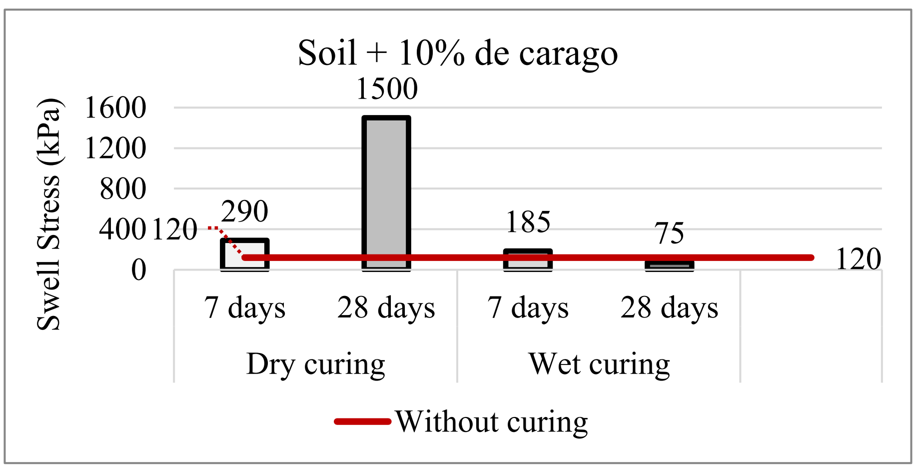


Figure 20 – Comparison of Swell Stress among the samples with 10% carago with no curing and with 7 and 28 days of curing.
Source: Authors (2025).

The sample subjected to 28 days of dry curing showed the highest increase in free swell, with a rise of 262%, although it showed no variation at 7 days. Under wet curing, there was still an increase of 9% at 7 days and 21% at 28 days.

This sample showed the same swell stress at 28 days as the sample containing 5% *carago*. However, since the initial value at zero days was lower, the variation was greater, reaching 1150%. These increases in the *carago* samples are higher than those observed for the pure soil shown previously in Figure 11, indicating that, at longer dry curing times, the *carago* amplified the swell stress. Under wet curing at 28 days, however, there was a 37.5% reduction in swell stress, which was the only negative variation observed in the samples.

The longest period of dry curing resulted in an increase in both free swell and swell stress of the soil. The exception was the sample containing 10% *carago* and cured for 7 days, which showed no variation in free swell. This increase under dry curing is attributed to initial shrinkage caused by moisture loss, which led the samples to absorb more water and expand more during the tests compared to those subjected to other curing processes.

However, under wet curing, the increase in these parameters was significantly smaller: swell stress showed no increase in the pure soil (28 days) and a decrease in the sample with 10% *carago* (28 days).

Finally, the addition of 10% *carago* resulted in a reduction of the soil's free swell (at 7 kPa) in all samples, under both types of curing, when compared to the pure soil. This confirms the stabilization effect of the *carago*, indicating the need for further studies with higher percentages to determine the optimal content that maximizes the reduction of swell or ensures complete stabilization. According to Abdolvand and Sadeghiamirshahidi (2024), this reduction in swelling is caused by cation exchange: calcium ions from the *carago* replace monovalent cations, increasing the bonding between particles and reducing swelling.

4. Final Considerations

This experimental study aimed to understand the influence of adding *carago* and the curing time on the swelling potential of an expansive soil from the city of Mossoró/RN. Based on the results obtained, the following conclusions can be drawn.

Regarding the influence of *carago* addition on the soil, it was observed that the specific gravity of the solids in the mixtures decreased when the *carago* content was increased. This was expected, as the *carago* has a lower specific gravity than the soil under study. In the Standard Proctor compaction test, the addition of *carago* increased the maximum dry density and caused little variation in the optimum moisture content. Being finer in particle size, the *carago* filled the soil voids. Furthermore, free swell was reduced in all samples with 10% *carago* compared to the pure soil samples, regardless of curing time or type. Notably, there was a 25% reduction in free swell for the samples with 10% *carago* and 7 days of wet curing compared to the pure soil sample of the same age. Furthermore, swell stress increased in all the *carago* samples subjected to dry curing compared to the pure soil, except for the sample with 10% *carago* and no curing, which showed a value equal to that of the pure soil.

Regarding the influence of curing time and type, it was observed that longer periods of dry curing increased both free swell and swell stress in all samples subjected to this type of curing. Longer wet curing periods also increased free swell and swell stress, although the increases were smaller compared to dry curing.

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