THE INFLUENCE OF SAND AND CEMENT ON THE LATERITIC SOIL COMPACTION WITH IRON ORE TAILINGS

INFLUÊNCIA DA AREIA E DO CIMENTO NA COMPACTAÇÃO DE SOLO LATERÍTICO COM REJEITO DE MINÉRIO DE FERRO

INFLUENCIA DE LA ARENA Y DEL CEMENTO EN LA COMPACTACIÓN DE SUELO LATERÍTICO CON RESIDUOS DE MINERAL DE HIERRO

JHADE IANE CUNHA VIMIEIRO, MSc. | UFMG – Universidade Federal de Minas Gerais, Brasil
SOFIA ARAÚJO LIMA BESSA, PhD | UFMG – Universidade Federal de Minas Gerais, Brasil
TALITA CAROLINE MIRANDA, PhD | UFMG – Universidade Federal de Minas Gerais, Brasil
LORENA ANDRADE DE FREITAS SILVA | UFMG – Universidade Federal de Minas Gerais, Brasil
ANA CAROLINA SANTANA ARANTES | UFMG – Universidade Federal de Minas Gerais, Brasil

ABSTRACT
The characteristics of lateritic soils vary significantly, depending on the laterization process they have undergone. Due to this diversity, physicochemical and mechanical tests may be necessary to assess the feasibility of using it. This research aimed to characterize the soil and sedimented iron ore tailings (IOT) and analyze, through compaction tests, the influence of the Portland cement and the sand in the mixtures used for rammed earth (RE) construction. Three groups were proposed for compaction tests: Group 1 (reference – only soil), Group 2 (40% sand + soil), and Group 3 (40% sand + 2.5% Portland cement). Each group consisted of five mixtures with varying content of soil replacement by IOT. The results showed that, although Groups 2 and 3 increased the maximum dry density values in the mixtures without IOT compared to Group 1, the mixtures did not reach the minimum requirements specified by the Brazilian standard for RE. Additionally, the mixtures without IOT presented high optimal moisture content. The use of IOT in mixtures positively reduced the optimum water content and increased the dry density values, which are important parameters to RE production.

KEYWORDS
Compaction test; Lateritic soil; Iron ore tailings; Rammed earth.

RESUMO
As características dos solos lateríticos variam significativamente, dependendo do processo de laterização a que foram submetidos. Devido a essa diversidade, análises físico-químicas e mecânicas podem ser necessários para avaliar a viabilidade. Esta pesquisa teve como objetivo caracterizar o solo e os rejeitos de minério de ferro sedimentados (RMF) e analisar, por meio de testes de compactação, a influência do cimento Portland e da areia nas misturas usadas para a taipa de pilão. Três grupos foram propostos para os testes de compactação: Grupo 1 (referência), grupo 2 (40% de areia) e grupo 3 (40% de areia e 2,5% de cimento Portland). Cada grupo consistia em cinco misturas com conteúdo variável da substituição do solo pelo RMF. Os resultados mostraram que, embora os Grupos 2 e 3 tenham aumentado os valores máximos de densidade seca nas misturas sem RMF em comparação ao Grupo 1, as misturas não atingiram os requisitos

mínimos especificados pela norma brasileira de taipa de pilão. Além disso, as misturas sem RMF apresentaram elevado teor de umidade. O uso do RMF em misturas reduziu a quantidade de água ótima para compactação e aumentou os valores de densidade seca, que são parâmetros importantes para a produção da taipa de pilão.

PALAVRAS-CHAVE
Ensaio de compactação; solo laterítico; rejeito de minério de ferro; taipa de pilão.

RESUMEN
Las características de los suelos lateríticos varían significativamente, dependiendo del proceso de laterización al que hayan sido sometidos. Debido a esta diversidad, pueden ser necesarios análisis físico-químicos y mecánicos para evaluar la viabilidad. Esta investigación tuvo como objetivo caracterizar el suelo y los residuos de mineral de hierro sedimentados (RMF) y analizar, a través de pruebas de compactación, la influencia del cemento Portland y de la arena en las mezclas utilizadas para la tierra apisonada. Se propusieron tres grupos para las pruebas de compactación: Grupo 1 (referencia), Grupo 2 (40% de arena) y Grupo 3 (40% de arena y 2,5% de cemento Portland). Cada grupo consistía en cinco mezclas con contenido variable de sustitución del suelo por RMF. Los resultados mostraron que, aunque los Grupos 2 y 3 aumentaron los valores máximos de densidad seca en las mezclas sin RMF en comparación con el Grupo 1, las mezclas no cumplieron con los requisitos mínimos especificados por la norma brasileña de tierra apisonada. Además, las mezclas sin RMF presentaron un alto contenido de humedad. El uso de RMF en las mezclas redujo la cantidad de agua óptima para la compactación y aumentó los valores de densidad seca, que son parámetros importantes para la producción de tierra apisonada.

1. INTRODUCTION

Laterization is a natural process of rock degradation caused by atmospheric and geological conditions (KUMAR *et al*., 2022). Lateritic soils are the product of this weathering process, originating from composed rocks essentially by iron, aluminum, and quartz oxides, being common in tropical and subtropical regions (CASTRO *et al*., 2020). About 8% of the earth's surface is covered by lateritic soils, with Brazil presenting its occurrence in almost all regions.

Although laterization is a natural process, climate change and soil desertification have intensified this phenomenon, intensifying the natural process. The fine particles of lateritic soil have caused air pollution around the world (KUMAR *et al*., 2022). Thus, it becomes essential to investigate in detail the behavior of lateritic soils in various applications, especially in lower environmental impact solutions.

Lateritic soils may have different characteristics and behaviors due to the diversity of their original rocks and the process of weathering. This process can result in variations in the structure, chemical composition, and granulometry. Consequently, the structural, chemical, and mineralogical properties are modified (CAMAPUM, 2004).

Lateritic soil structure can change their void rates and the size and volume of the pores. Concerning granulometry and mineralogical properties, lateritic soils, because they have high fine content, are strongly influenced by the clay fraction.

The clay fraction of these soils is predominantly composed of the kaolinite group (Luciano *et al*., 2012) and has a high concentration of iron and aluminum oxides (Pinto, 1998). Among the main three clay minerals, kaolinite has the largest surface area, but the lowest clay activity (DAS, 2007). Its structure consists of the repetition of layers of elementary gibbsite and silica blades in a 1:1 crystalline network. The presence of poorly expansive clay is frequent in lateritic soils in tropical climate regions, such as the Minas Gerais region, in which the laterization is conditioned by soil leaching (VALE, 2020).

Because of its heterogeneity, lateritic soils present changes in geotechnical characteristics such as Atterberg limits, specific density, and humidity (KUMAR *et al*., 2022), and it isn't easy to estimate their behavior when submitted to climate change (CAMAPUM, 2004). Therefore, it may be necessary to conduct physicochemical and mechanical tests to evaluate the feasibility of using lateritic soil (Araújo and Farias, Araújo, Rodrigues, 2023).

The compaction test is a common practice used for soil study. In a natural state, the soil has a high void ratio that is filled with air. During compaction, mechanical energy application removes air, increasing soil density and reducing its empty spaces (BARROS *et al*., 2021). Through compaction tests, it is possible to determine the maximum dry density (MDD) and optimum moisture content (OMC).

In addition to that, the rammed earth (RE) technique also benefits from the knowledge that can be acquired in the compaction test because it is one of the parameters required by NBR 17014 (ABNT, 2022), reinforcing its importance.

Rammed earth is a low environmental impact constructive technique in which the wall is performed with compacted soil within removable formwork, resulting in a monolithic element. Thus, proper compaction can increase the wall resistance. However, some authors attest that the RE vulnerability increases when lateritic soils are used because these soils change their properties by interacting with the atmosphere (Wahab *et al*., 2021).

The use of stabilizers can improve the physical and mechanical characteristics of lateritic soils. Several research works have been carried out on the use of cement and lime for lateritic soil stabilization. However, cement production has a high environmental impact, and its use should be reduced whenever possible.

Wahab et al. (2021) studied the influence of 3, 6, 9, and 12% of cement addition on lateritic soil on compaction, durability, and compressive strength. Soil compaction increased as cement was added. Caro et al. (2018) analyzed that between 2% and 6% of cement may be sufficient to stabilize lateritic soils.

Some research has used industrial waste for lateritic soil stabilization. Obianyo et al. (2021) studied Nigerian lateritic soil stabilization with 2% bone ash and 2% palm ash for adobes production. The authors concluded that the bone ash and palm ash addition contributed to a relevant increase in compressive strength.

Oluremi and Ishola (2024) investigated the efficacy of the Arabic gum biopolymer as an additive to increase the mechanical resistance of Nigerian lateritic soil, as used for paving. The authors attested that using 10% biopolymer increased the MDD and decreased the OMC.

Another study used contaminated sand with oil for lateritic soil stabilization. The authors concluded that using up to 20% of contaminated sand could be adequate for soil stabilization (ABDELIMALI *et al*., 2021).

Lage *et al*. (2022) used sedimented iron ore tailings (IOT) by soil replacement for lateritic soil stabilization, in southeastern Brazil, for RE production. The authors demonstrated that compaction increased and OMC decreased as the IOT was added.

Thus, different stabilizers have been discussed in the literature, and the use of industrial waste is a viable alternative to mitigate the environmental impact of soil stabilization.

Iron ore tailings are by-products originating from the iron ore process, mainly in Brazil, China, and Australia. Despite high profits, one of the main environmental issues associated with iron extraction is the amount of tailings generated during the process and their environmental consequences.

In 2015, the Fundão dam collapsed in Bento Rodrigues, a little community belonging to the municipality of Mariana, Minas Gerais. The dam's storage was 55 million cubic meters of iron ore tailings (IOT) resulting in the IOT displacement through the rivers, where it was sedimented at the bottom (SEMAD, 2016). Sedimented IOT samples were dredged and are available for proper use.

Considering the wide availability of lateritic soils in Brazil and the need to use them in low environmental impact constructive solutions, especially in response to the growing demand for the urgent destination of IOT, this paper aimed to analyze the lateritic soil stabilization by compaction tests with IOT incorporation. Sand and Portland cement were added to the mixtures to make them suitable for the RE technique.

This research aimed to provide adequate use for sedimented IOT, which is currently stored without the correct destination. In addition, it can expand knowledge about lateritic soil stabilization for RE production, which is necessary for its dissemination and application.

2. MATERIALS AND METHODS

The materials used in this study were: the lateritic soil, IOT samples, Portland cement, and natural sand. The soil used was collected from the central region of the state of Minas Gerais, the Southeast region of Brazil (Figure 1). The IOT collection was carried out in the municipality of Barra Longa, at Alta Floresta Farm, which became a surplus deposition and management area five years after the failure of the Fundão dam (Mariana, Minas Gerais).

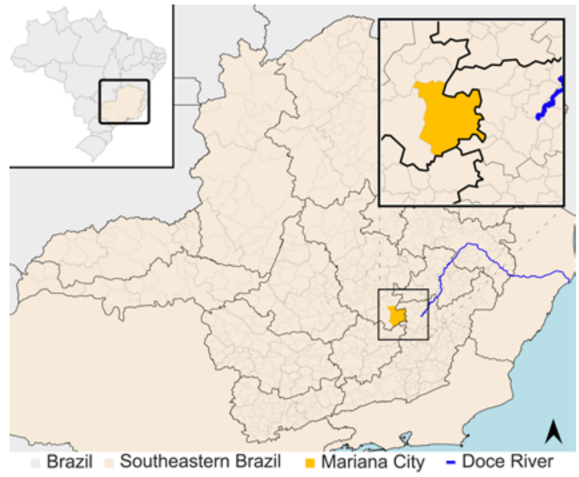

Figure 1: Map - Location of Mariana City and Doce River.
Source: Authors.

Soil and IOT were analyzed by the following tests: i) mineralogical characterization was performed by X-ray diffraction (XRD); ii) chemical characterization was performed by X-ray fluorescence spectrometry (XRF); and physical characterization was carried out by granulometry (NBR 7181, 2016a), and Atterberg limits (NBR 6459, 2016b and NBR 7180, 2016c). Table 01 presents the tests and results obtained.

Clay activity influences soil plasticity. It was observed that the soil used in the mixtures has a high clay content but has low plasticity due to the type of clay, the kaolinite (HOFFMANN, MINTO, HEISE, 2011).

Soil Plasticity Index (PI) was equal to 2% and clay fraction was equal to 35%, so the Clay Activity (CA) of the soil was calculated at 0.06%. The clays are considered inactive when the CA is less than 0.75%, which confirms the XRD and XRF results, which presented a predominance of kaolinite which is a low-activity clay (SKEMPTOON, 1953).

Low clay activity indicates greater soil stability, lower variations in water content, fewer volume changes when damp, and lesser shrinkage when dry, compared to materials that have the highest clay activity (KOUTOUS, HILALI, 2019).

Properties	Soil	IOT
Clay (%)	35.0	9.0
Silt (%)	19.0	35.0
Sand (%)	45.8	52.0
Gravel (%)	0.2	4.0
Liquidity Limit (%)	41.0	20.0
Plasticity Limit (%)	39.0	NP
Plasticity Index – PI (%)	2.0	-

Table 1: Soil and IOT characterisation and classification.
Source: Authors.

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XRD analysis showed a predominance of the kaolinite, quartz, and goethite minerals in the soil. The sample of IOT presented quartz and hematite as predominant minerals. It suggests that the sedimented IOT maintained characteristics like the IOT found in dams, even after the tailings have spread and have mixed in the environment. In the chemical analysis by XRF, both in the soil and in the IOT sample, significant proportions of the alumina (Al_2O_3), silica (SiO_2), and hematite (Fe_2O_3) minerals were identified. The latter was also observed in the XRD test.

Additionally, IOT samples were subjected to leaching and solubilization tests, according to NBR 10005 and 10006 (ABNT, 2004b,c) to classify them by hazardousness, according to NBR 10004 (ABNT, 2004a). IOT collected in Barra Longa was classified as Class II A - not dangerous and not inert, as it contains iron, aluminum, and manganese in content above the upper established limit.

The sand sample used in this research is the commercial-washed medium type. The maximum characteristic dimension value of the sand was 2.36 mm, and the fineness modulus was 2.44 mm. Sand and IOT were added to the mixtures to achieve the granulometric guidelines defined by the Brazilian rammed earth standard, NBR 17014 (ABNT, 2022).

Cement was added to analyze the impact on mechanical strength, durability, and the effect of raising the pH value. The cement used was type CPII-F 32 (Portland composite cement) with clinker + calcium sulfate partially replaced by limestone filler - clinker + calcium sulfate = 75-89%; and filler = 11-25% (ABNT, 2018), as it is one of the most common cement in Brazil. CP II – F is equivalent to ASTM limestone cement (IL) and, depending on the composition proportion and material quality, can be equivalent to BSI CEM II A-L, ALL, B-L, or B-LL (NATALLI *et al*., 2021).

2.1 Samples preparation

The mixtures produced with IOT as a soil replacement were defined based on the results obtained in the characterization of materials, to reach the requirements of NBR 17014 (ABNT, 2022). Then, the mixtures must follow a) 50% to 80% of retained material between sieves with mesh openings of 0.075 mm and 2.0 mm; b) 20% to 35% of material that passes in the sieve with a mesh opening of 0.075 mm.

Based on these requirements, NBR 17014 (ABNT, 2022) classifies clay and silt fractions below 0.075 mm grain size and sand fractions between 0.075 mm to 2.0 mm. For a definition, the clay is classified as all particles with Ø ≤ 0.002 mm; the silt is between 0.002 mm and 0.075 mm; and the sand is between 0.075 mm and 2 mm.

So, Group 1 was composed of five mixtures, with two reference samples (100% soil and 100% IOT), while the other three consisted of soil and IOT mixtures. The mixtures were named according to the soil replacement by IOT. Even with high soil replacement by IOT, it was observed that it was not possible to reach the "clay + silt" values specified in NBR 17014, as shown in Table 2.

Group 2 was defined with the addition of natural sand aiming for the granulometric correction of Group 1. The sand addition is a recommended practice by NBR 17014 (ABNT, 2022). The letter 'S' was added to nominate the Group 2. Table 3 shows the mixtures and proportions of Group 2.

Mixtures	Soil (%)	IOT (%)	Clay+ Silt (%)	Sand (%)
0	100	0	74.05	25.72
70	30	70	57.87	39.00
80	20	80	50.01	46.18
90	10	90	46.82	49.01
100	0	100	44.0	52.00

Table 2: Mixtures and proportions of materials - Group 1.
Source: Authors.

In addition to the granulometric correction with sand, 2.5% of cement was added to the mixtures, in Group 3, to analyze the cement's impact on the durability and mechanical behavior of the mixtures.

The cement content was chosen to seek the benefits of stabilization with the lowest cement content, due to the high environmental impact of the material. This content was defined after literature analysis (ARRIGONI *et al*., 2017; TOUFIGH, KIANFAR, 2019; ZAMI *et al*., 2022). The letters "SC" were added to nominate the Group 3.

Mixtures	Soil (%)	IOT (%)	Sand (%)	Clay+ Silt (%)	Total Sand (%)
0-S	100	0	40	52.89	46.94
70-S	30	70	40	37.87	60.28
80-S	20	80	40	35.72	61.96
90-S	10	90	40	33.58	63.84
100-S	0	100	40	31.43	65.71

Table 3: Mixtures and proportions of materials - Group 2.
Source: Authors.

Table 04 presents a summary of the groups, the nomenclatures used, and the proportion of materials.

Group	Mixtures	Soil (%)	IOT (%)	Sand (%)	Cement (%)
1	0	100	0	-	-
	70	30	70	-	
	80	20	80	-	
	90	10	90	-	
	100	0	100	-	
2	0-S	100	0	40	-
	70-S	30	70	40	
	80-S	20	80	40	
	90-S	10	90	40	
	100-S	0	100	40	
3	0-SC	100	0	40	2.5
	70-SC	30	70	40	
	80-SC	20	80	40	
	90-SC	10	90	40	
	100-SC	0	100	40	

Table 4: Description of mixtures and material contents.
Source: Authors.

2.2 Compaction test

The compaction test, as established by NBR 7182 (ABNT, 2016d), was carried out to determine the moisture content necessary to compact the soil until reaching the maximum dry density, considering the compaction energy.

The small Proctor Hammer (2.5 kg) was used, with three layers of 26 blows per layer, as required on technical standard (NBR 7182), for normal compaction energy. To prevent the wet mixture from adhering to the bottom of the proctor, a filter paper has been positioned inside the mold.

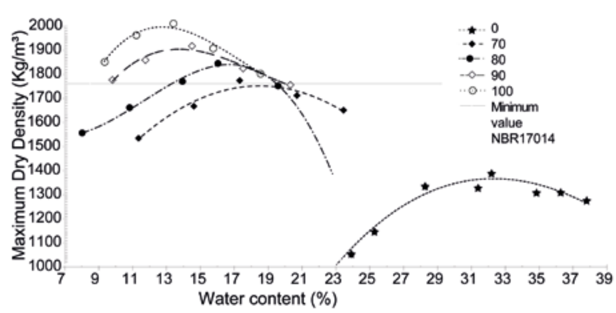
After compaction, the specimen was extracted with the help of the extractor. A little sample was removed from the center of the specimen to determine the moisture to obtain the compaction curve. According to NBR 17014 (ABNT, 2022), the mixture must reach a dry density value greater than or equal to 1750 kg/m^3, similar to those established in other countries (ÁVILA, PUERTAS, GALLEGO, 2021; LOSINI *et al*., 2022).

3. RESULTS AND DISCUSSION

Graphic 1 shows the results of the compaction test in Group 1. It is possible to observe that the mixtures 0 and 70 did not reach the MDD and presented high values of OMC.

The high moisture of soil compaction can be partially attributed to the high content of alumina (Al_2O_3) present in the soil. Alumina acts as a natural adsorbent owned by retaining liquids on its surface (PHAM *et al*., 2019).

If the RE mixtures show a high optimum moisture content (OMC) it is possible to observe four main disadvantages: i) contemporary, due to the limited water resources in many countries (ZAMI *et al*., 2022); II) The high water content may lead to retraction and deformation in RE during the drying process and evaporation of water (KOUTOUS, HILALI, 2019); iii) Excessive soil moisture may result in adherence to it to forms and other work equipment during RE molding (HOFFMANN, MINTO, HEISE, 2011); and iv) mechanical resistance tends to increase with the reduction in the OMC (Chauhan *et al*., 2019; JAQUIN *et al*., 2009).



Graphic 1: Dry density versus water content - Group 1.
Source: Authors.

Figure 2 shows the adherence of the mixture into the molds during the RE samples production. However, it is

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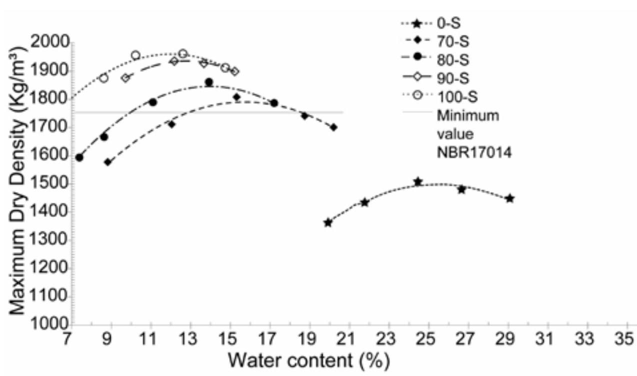
important to understand that the proctor compaction test does not apply the same energy as the mechanical compactor equipment used on the construction site. This means that the OMC, determined by the compaction test, can be excessively high (MESBAH, MOREL, OLIVER, 1999).

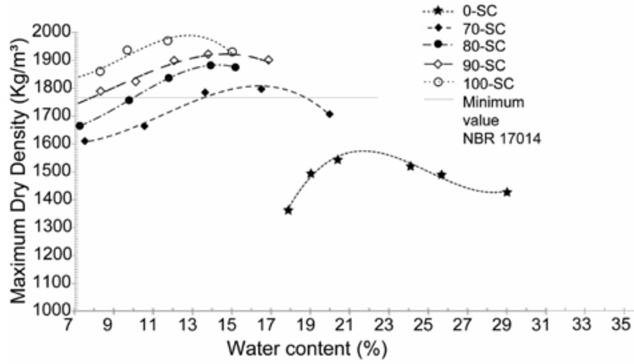
Figure 2: Adherence of the mixture (0% - Group 1) to the mold.
Source: Authors.

Graphic 2 shows the compaction test of Group 2. In mixtures 80-S, 90-S, and 100-S, it is possible to observe an increase in MDD as it increased the IOT content in the mixture, similar to Group 1.

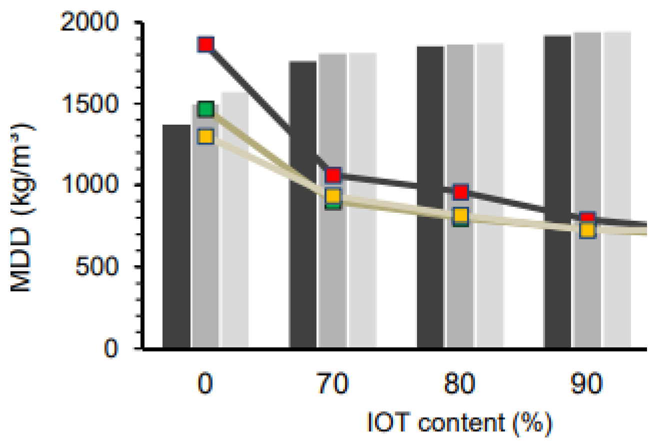


Graphic 2: Dry density versus water content - Group 2.
Source: Authors.

The sand addition has resulted in the reduction of OMC in all mixtures. The 0-S mixture was the most affected by the impact of the sand addition, with a 22% decrease in the OMC compared to Group 3 mixtures (Graphic 3). For a better comparative analysis and a better understanding of the impact of additions on mixtures, Graphic 4 was prepared.



Graphic 3: Dry density versus water content - Group 3.
Source: Authors.



Graphic 4: Dry density versus optimum water content.
Source: Authors.

It is noteworthy that correction with sand has a significantly greater and positive impact on mixtures produced without IOT or with a low content of IOT. This fact occurred because both sand and IOT act similarly in the mixture but considering that IOT is thinner than sand used.

Thus, in IOT-only mixtures, the sand and the cement do not affect the OMC and the MDD. The increase in dry density in mixtures with sand and cement addition can be explained by the contribution of sand to a uniform granulometric distribution, resulting in a more appropriate grain packaging and, consequently, a higher dry density (HOFFMANN, MINTO, HEISE, 2011).

There is also a tendency for the dry density of mixtures to increase as IOT content increases.

4. CONCLUSIONS

After the analysis, it was possible to conclude:

1. The lateritic soil studied did not reach the MDD required by NBR 17014. In addition, it presented a high humidity of compaction, resulting in soil adherence to the mold.
2. The sand addition for granulometric correction in the mixtures has reduced the OMC for compaction without significantly affecting the MDD of mixtures with higher IOT content.
3. In IOT mixtures, the cement did not significantly influence the OMC or the MDD.
4. The use of IOT in mixtures positively reduced the OMC and increased the dry density values, which are important parameters to RE production.

REFERENCES

ABDELHALIM, R. A.; RAMLI, H.; SELAMAT, M. R. Cone penetration measurements in oil-contaminated sand stabilized by lateritic soil and potencial usage in concrete mix. **Case Studies in Construction Materials**, v. 15, 2021. Disponível em: https://doi.org/10.1016/j.cscm.2021.e00580. Acesso em: 24 ago. 2024.

ASSOCIAÇÃO BRASILEIRA DE NORMAS TÉCNICAS. **NBR 6459**: solo: determinação do limite de liquidez. Rio de Janeiro, 2016b.

ASSOCIAÇÃO BRASILEIRA DE NORMAS TÉCNICAS. **NBR 7180:** solo: determinação do limite de plasticidade. Rio de Janeiro, 2016c.

ASSOCIAÇÃO BRASILEIRA DE NORMAS TÉCNICAS. **NBR 7181:** solo: análise granulométrica. Rio de Janeiro, 2016a.

ASSOCIAÇÃO BRASILEIRA DE NORMAS TÉCNICAS. **NBR 7182:** solo: ensaio de compactação. Rio de Janeiro, 2016d.

ASSOCIAÇÃO BRASILEIRA DE NORMAS TÉCNICAS. **NBR 10004:** resíduos sólidos: classificação. Rio de Janeiro, 2004a.

ASSOCIAÇÃO BRASILEIRA DE NORMAS TÉCNICAS. **NBR 10005:** procedimento para obtenção de extrato lixiviado de resíduos sólidos. Rio de Janeiro, 2004b.

ASSOCIAÇÃO BRASILEIRA DE NORMAS TÉCNICAS. **NBR 10006:** procedimento para obtenção de extrato solubilizado de resíduos sólidos. Rio de Janeiro, 2004c.

ASSOCIAÇÃO BRASILEIRA DE NORMAS TÉCNICAS. **NBR 16697:** cimento portland: requisitos. Rio de Janeiro, 2018.

ASSOCIAÇÃO BRASILEIRA DE NORMAS TÉCNICAS. **NBR 17014:** taipa de pilão: requisitos, procedimentos e controle. Rio de Janeiro, 2022.

ARAÚJO E FARIAS, M. L.; ARAÚJO, H. A.; RODRIGUES, J. K. Análise da aplicabilidade de sistema de classificação universal para solos lateríticos utilizados em camadas de pavimentos. **Transportes**, v. 31, n. 1, p. 2750, 2023. Disponível em: https://doi.org/10.58922/transportes.v31i1.2750. Acesso em: 20 jul. 2024.

ARRIGONI, A.; BECKETT, C.; CIANCIO, D.; DOTTELI, G. Life cycle analysis of environmental impact vs. durability of stabilised rammed earth. **Construction and Building Materials**, v. 142, p. 128–136, 1 jul. 2017. Disponível em: http://dx.doi.org/10.1016/j.conbuildmat.2017.03.066. Acesso em: 20 jul. 2024.

AVILA, F.; PUERTAS, E.; GALLEGO, R. Characterization of the mechanical and physical properties of unstabilized rammed earth: a review. **Construction and Building Materials**, v. 270, p. 121435-121446, 2021. Disponível em: https://doi.org/10.1016/j.conbuildmat.2020.121435. Acesso em: 20 jul. 2024.

Barros, D. do S., Pereira, P. H. dos S., Motter, H., Santos, A. dos. Compactação de solo: indíces físicos necessários para determinação dos fatores de compactação. **Pesquisa e Ação**, v.7, n.1, p, 51–64. 2021.

CAMAPUM, J. C. Propriedades e comportamento de solos tropicais não-saturados. In: 5º Simpósio Brasileiro de Solos Não Saturados, São Carlos, **Solos Não Saturados.** Vilar, O. M., EESC-USP, v. 2, p. 1-2, 2004.

Advanced characterisation of cement-stabilised lateritic soils to be used as road materials. **International Journal of Pavement Engineering**, v. 20, p. 1425–1434. 2018. Disponível em: https://doi.org/10.1016/j.rcradv.2022.200120. Acesso em 22 mar. 2024.

CASTRO, Marcus D.; OLIVEIRA, Vinícius N.; MASCARENHA, Márcia M.A.; GITIRANA JUNIOR, Gilson de F.N.; LUZ, Marta P. Análise das curvas características solo-água de amostras remoldada e indeformada de um solo laterítico não saturado. In: XX Congresso Brasileiro de Mecânica dos Solos e Engenharia Geotécnica, 2020. **Anais** [...]. Campinas, 2020.Disponível em: https://www.researchgate.net/publication/362144568_Analise_das_curvas_caracteristicas_solo-agua_de_amostras_remoldada_e_indeformada_de_um_solo_lateritico_nao_saturado. Acesso em: 20 jul. 2024.

DAS, Braja M.; SOBHAN, Khaled. **Fundamentos de engenharia geotécnica**. 6. ed. São Paulo: Thompson, 2007.

HOFFMANN, M.; MINTO, F.; HEISE, A. Taipa de pilão. In: NEVES, Célia; FARIA, Obede Borges (org.). **Técnicas de construção com terra.** Bauru, SP: FEB-UNESP/PROTERRA, 2011. p. 1–79. E-book. Disponível em: www.redproterra.org. Acesso em: 22 ago. 2024.

JAQUIN, P. A.; AUGARD, C. E.; GALLIPOLI, D.; TOLL, D. G. The strenght of unstabilised rammed earth materials. **Geotecnique**, v.59, p. 487-490. Disponível em: http://dx.doi.org/10.1680/geot.2007.00129. Acesso em 24 de jul. 2024.

KOUTOUS, A.; HILALI, E. M. A Proposed Experimental Method for the Preparation of Rammed Earth Material. **International Journal of Engineering Research & Technology**, 2019. Disponível em: http://dx.doi.org/10.17577/IJERTV8IS070140. Acesso em: 20 jul. 2024.

KUMAR, S. G.; SAINI, P. K.; DEOLIYA, R. MISHRA, K. Characterization of laterite soil and its use in construction applications: A review. **Resources, Conservation and Recycling Advances**, v. 16, n. 200120, 2022. Disponível em: https://doi.org/10.1016/j.rcradv.2022.200120. Acesso em: 20 jul. 2024.

LAGE, Gabriela T. de L.; BESSA, Sofia, A. L.; SANTOS, Beatriz F. A. dos; MATIAS, L. M. GALERY, Roberto. **Potencial de estabilização da taipa de pilão com rejeitos de mineração e cal**. 11 nov. 2023, [S.l.]: ANTAC, p. 1–6, 2023. Disponível em: https://www.researchgate.net/publication/375578606. Acesso em: 20 jul. 2024.

LOSINI, Alessia E.; GRILLET, Anne-Cecile; WOLOSZYN, Monika; LAVRIK, Liudmila; MOLETTI, Chiara; DOTELLI, Giovanni; CARUSO, Marco. Mechanical and microstructural characterization of rammed earth stabilized with five biopolymers. **Materials**, v. 15, n. 9, 1 maio 2022. Disponível em: https://doi.org/10.3390/ma15093136. Acesso em: 20 jul. 2024.

Natalli, J.F.; Thomaz, E.C.S.; Mendes, J.C.; and Peixoto, R.A.F., 2021. A review on the evolution of Portland cement and chemical admixtures in Brazil. **IBRACON Estrut. Mater.**, 14 (2021), e14603.

MESBAH, A. A. M.; MOREL, J. C.; OLIVER, M. Clayey soil behaviour under static compaction test. **Material and Structures**, v. 32, n.9, p. 687- 694, 1999. Disponível em: https://link.springer.com/content/pdf/10.1007/BF02481707.pdf . Acesso em 24 ago. 2024.

OBIANYO, I. O.; MAHAMAT, A. A.; ANOSIKE-FRANCIS, E. N.; STANISLAS, T. T.; GENG, Y.;ONYELOWE, K. C.; ODUSANYA,S.; ONWUALU, A. P.; SOBOYEJO, A. B. O. Perormance of lateritic soil stabilized with combination of bone and palm bunch ash for sustainable building applications. **Cogent Engineering**, v. 8, n.1921673. 2021. Diponível em: https://doi.org/10.1080/23311916.2021.192167. Acesso em 24 jul. 2024.

OLUREMI, J. R.; ISHOLA, K. Compaction and strength characteristics of lead contaminated lateritic soil treated with eco-friendly biopolymer for use as road foundation material. **Hybrid advances**, v. 5, n. 100158. 2024. Disponível em: https://doi.org/10.1016/j.hybadv.2024.100158. Acesso em: 24 ago. 2024.

PANAGIOTOU, R.; KYRIAKIDES, M.A.; ILLAMPAS, R.; LOANNOU, I. An experimental approach for the investigation of the performance of non-stabilized Compressed Earth Blocks (CEBs) against water-mediated weathering. **Journal of Cultural Heritage**, v. 57, p. 184–193, 1 set. 2022. Disponível em: https://doi.org/10.1016/j.culher.2022.08.009. Acesso em: 20 jul. 2024.

PINTO, C. de S. Propriedades dos solos. In: FALCONI, F.; CORRÊA, C. N.; ORLANDO, C.; SCHIDT, C.; ANTUNES, W. R.; ALBUQUERQUE, P. J. HACHICH, W.; NIYAMA, S. (org.). **Fundações: teoria e prática.** 3. ed. São Paulo: Oficina de textos, 2019. Disponível em: Acesso em Artmed, 2014. p. 25-72. Disponível em: http://ofitexto.

arquivos.s3.amazonaws.com/degustacao/fundacoes--teoria-e-pratica_deg.pdf. Acesso em: 24 ago. 2024.

PHAM, Tien Duc; TRAN, Thi T.; LE, Van, A.; PHAM, Thu T.; DAO, Thi H.; LE Thanh S.L. Adsorption characteristics of molecular oxytetracycline onto alumina particles: The role of surface modification with an anionic surfactant. **Journal of Molecular Liquids**, v. 287, 1 ago. 2019. Disponível em: https://doi.org/10.1016/j.molliq.2019.110900. Acesso em: 20 jul. 2024.

SEMAD. **Desastre Ambiental em Mariana e Recuperação do Rio Doce**. Disponível em: https://www.meioambiente.mg.gov.br/component/content/article/13-informativo/2879-desastre-ambiental--em-mariana-e-recuperacao-da-bacia-do-rio-doce. Acesso em: 20 jul. 2024.

SKEMPTON, A. W. The Colloidal "Activity" of Clays: l'activité colloïdale des argiles. 3RD **International conference on soil mechanics and foundation engineering**, 3., 1953, Suíça. International society for soil mechanics and geotechnical engineering, 1953. p. 57–61. Disponível em: https://www.issmge.org/publications/online-library. Acesso em: 20 jul. 2024.

TOUFIGH, Vahab; KIANFAR, Ehsan. The effects of stabilizers on the thermal and the mechanical properties of rammed earth at various humidities and their environmental impacts. **Construction and Building Materials**, v. 200, p. 616- 629. 2019. Disponível em: https://doi.org/10.1016/j.conbuildmat.2018.12.050. Acesso em: 20 jul. 2024.

WAHAB, Norshakila A. ROSHAN, Mohammad J.; RASHID. Ahmad S.A.; HEZMI, Muhammad A.; JUSOH, Siti N.; NORSYAHARIATI, Nik D.; TAMASSOKI, Sakina. Strength and durability of cement-treated lateritic soil. **Sustainability** (Switzerland), v. 13, n. 11, 2021. Disponível em: https://doi.org/10.3390/su13116430. Acesso em: 20 jul. 2024.

ZAMI, Mohammed S.; EWEBAJO, Adeoluwa O.; AL-AMOUDI, Omar S.B.; AL-OSTA, Mohammed A.; MUSTAFA, Yassir M.H. Compressive strength and wetting–drying cycles of Al-Hofuf "Hamrah" soil stabilized with cement and lime. **Arabian Journal for Science and Engineering**, v. 47, p. 13249- 13264, 2022. Disponível em: https://doi.org/10.1007/s13369-022-06576-0. Acesso em: 20 jul. 2024.

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AUTHORS:

ORCID: 0000-0001-8494-3038
JHADE IANE CUNHA VIMIEIRO, mestra em Ambiente Construído e Patrimônio Sustentável | Universidade Federal de Minas Gerais | Mestrado em Ambiente Construído e Patrimônio Sustentável | Belo Horizonte, MG - Brasil | Correspondência para: Av Marco Túlio Isaac, 9285, Nova Baden, Betim, MG, 32065-335 | E-mail: jhadevimieiro@gmail.com

ORCID: 0000-0003-1883-1251
SOFIA ARAUJO LIMA BESSA, Doutora em Engenharia Urbana | Universidade Federal de Minas Gerais | Programa de Pós-graduação em Ambiente Construído e Patrimônio Sustentável | Belo Horizonte, MG - Brasil | Correspondência para: (Rua Paraíba, 697, Savassi, Belo Horizonte, MG, 30130- 141) | E-mail: sofiabessa@ufmg.br

ORCID: 0009-0000-1008-2458
LORENA ANDRADE DE FREITAS SILVA, Graduanda em Arquitetura e Urbanismo | Universidade Federal de Minas Gerais | Arquitetura e Urbanismo | Belo Horizonte, MG - Brasil | Correspondência para: (Av. Afonso Pena, 1757, Centro, Belo Horizonte, MG, 30130-004) | E-mail: fandradelorena@gmail.com

ORCID: 0009-0006-6110-3144
ANA CAROLINA SANTANA ARANTES, Graduanda em Arquitetura e Urbanismo | Universidade Federal de Minas Gerais | Arquitetura e Urbanismo | Belo Horizonte, MG - Brasil | Correspondência para: (Rua Armando Bastos Gismont, 250A, Parque Rinald, Varginha, MG, 37036-080) | E-mail: acsntana@gmail.com

ORCID: 0000-0001-8202-8717
TALITA CAROLINE MIRANDA, Doutora em Engenharia Civil | Universidade Federal de Minas Gerais | Engenharia de Transportes e Geotecnia | Belo Horizonte, MG - Brasil | Correspondência para: Av. Pres. Antônio Carlos, 6627 - Pampulha, Belo Horizonte - MG, 31270-901 | Email: talita@etg.ufmg.br

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JICV: conceptualization, formal analysis, investigation, methodology, visualization, data curation, writing - original draft and writing - review & editing.

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TCM: methodology.

LAFS: investigation.

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