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Technological assessment of rendering mortar produced with expanded vermiculite

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ABSTRACT
The construction industry is associated with a high consumption of non-renewable resources, such as sand, in addition to the energy demand involved in the construction processes and the use of buildings. In the search for new technologies for traditional building materials, cement mortars have been modified by replacing sand with lightweight aggregates, such as expanded vermiculite. The aim of the present study is, therefore, to analyze the flexural tensile strength of rendering mortars produced with a 1:1:6 mix ratio by volume, with 10% and 20% substitution of natural aggregate by expanded vermiculite, comparing them with a reference mixture. The experimental phase consisted of the characterization of aggregates, preparation of mortars, tests in the fresh state, and flexural tensile strength tests. Overall, the replacement of sand with expanded vermiculite increased the flexural tensile strength, enhanced the fresh-state bulk density, and reduced the consistency index. Known for contributing to improvements in thermal and acoustic insulation, reducing structural weight, among other effects, the use of vermiculite in mortars demonstrated potential based on the results, as it did not significantly impair the mechanical behavior of the mixtures.

KEYWORDS: Fine aggregate. Mortar. Mechanical properties.

1 INTRODUCTION

Mortars, traditionally composed of binder, aggregate, and water, are frequently modified by substituting the aggregate. In recent years, there has been an increase in studies investigating the incorporation of lightweight aggregates in mortars. Lightweight aggregates, among other functions, are known to increase the void ratio and porosity while reducing density and thermal conductivity (Kwon *et al*., 2015).

For mortars intended for rendering walls and ceilings, NBR 13281-1 (ABNT, 2023) specifies the requirements and test methods. Primarily used to enhance thermal insulation (Passos & Carasek, 2018), expanded vermiculite has shown good results when incorporated into mortars.

In the overall construction scenario, and specifically in mortars, it can contribute, among other functions, to reducing structural weight (Cintra, Paiva & Baldo, 2014).

The investigation into the use of vermiculite represents an important tool in the search for cementitious materials with better thermal performance and, therefore, constructions with less environmental impact (Guilherme, 2019).

In addition to providing greater lightness and thermal insulation, the incorporation of vermiculite into construction materials represents an alternative for conserving natural sand deposits (Gencel *et al*., 2021).

1.1 Flexural Tensile Strength in Mortars with Aggregate Substitution

Regarding the mechanical performance of wall and ceiling rendering mortars, NBR 13279 (ABNT, 2005) specifies the tests for determining flexural tensile strength and compressive strength.

Barros (2018), Guilherme (2019), Sinhorelli (2019), Nascimento (2021), and Kaya and Köksal (2022) employed expanded vermiculite as a replacement for sand as an aggregate in mortars. In Barros (2018), Sinhorelli (2019), Nascimento (2021), and Kaya and Köksal (2022), the use of vermiculite resulted in a reduction in flexural tensile strength.

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In Guilherme's (2019) study, a slight variation in flexural tensile strength was observed in the mixes with added vermiculite, and a minor reduction was noted in the mix with 50% substitution. According to Nascimento (2021) and Kaya and Köksal (2022), the reduction in the mechanical strength of the mixtures can be attributed to the structure of expanded vermiculite itself, as it increases apparent porosity and water absorption.

Passos and Carasek (2018) used EPS (expanded polystyrene) waste as aggregates and observed lower flexural tensile strength in the mortars with waste compared to the reference mixture.

In Rocha (2019), the incorporation of recycled tire rubber waste into mortars led to a significant reduction in flexural tensile strength.

Akiniemy *et al*. (2020) adopted rice husk straw and observed an increase in flexural strength. The result, as noted by the authors, was similar to most studies that used plant-based aggregates.

Silva *et al*. (2021) studied mortars with wood waste replacing sand as an aggregate, and observed that higher waste content resulted in lower mechanical strength. In the mix with 5% waste, the flexural tensile strength was similar to that of the reference mix, while the mixture with 2.5% waste showed a lower strength.

Záleská *et al*. (2021) used expanded perlite, expanded glass, and zeolite in the mixtures and observed, in all investigated mixtures, a significant increase in mechanical strength as the curing age progressed.

Awoyera *et al*. (2022) used mineral wool and rice straw, and found that higher mineral wool fiber content resulted in lower flexural strength, diverging from the results of previous studies. At 7 days of age, all mortars with mineral wool and rice straw fibers showed higher flexural strength compared to the reference mortar, whereas at 14 and 28 days, only the mixture with 10% mineral wool achieved strength superior to that of the reference mix.

In El-Seidy *et al*. (2022), PVC and rubber waste were used in the mortars, and a progressive reduction in flexural strength was observed as the waste content increased. According to the authors, the smoother surfaces of PVC and rubber aggregates compared to the surface of sand are responsible for the reduction in mechanical performance.

Ferrandéz *et al*. (2022) adopted recycled thermal insulation waste composed of expanded polystyrene and mineral wool, and observed an increase in flexural strength in mortars with mineral wool fibers and a reduction in mixtures with polystyrene fibers.

In the work of Fontes *et al*. (2022), the incorporation of expanded clay as a replacement for sand resulted in similar values of flexural tensile strength across all mixes.

Given the importance of rendering mortars for the overall performance of buildings and the high consumption of this material in traditionally found constructions in Brazil, it is crucial to technologically evaluate the performance of mixes made with aggregate substitution. Thus, in this study, derived from an ongoing master's thesis, flexural tensile strength was adopted as the main test for discussing the mechanical behavior of the mixes.

2 OBJECTIVE

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Investigate the flexural tensile strength in rendering mortars produced with a 1:1:6 volumetric mix and made with 10% and 20% substitution of natural aggregate by expanded vermiculite.

3 METHODOLOGY

The first part of the study comprised the development of the theoretical framework, while the second part consisted of experimental analysis. The experimental phase involved the characterization of aggregates (sand and vermiculite), the preparation of mortars, and the evaluation of the mixes through tests in the fresh and hardened states.

The characterization of aggregates, the preparation of mixes, and the testing of mortars were conducted at the Civil Construction Laboratory of the Faculty of Engineering of Bauru (FEB), on the campus of São Paulo State University "Júlio de Mesquita Filho" (UNESP).

The binders used were Portland cement type CP II E-32 and hydrated lime type CH-III. The aggregates used—washed river quartz sand and expanded vermiculite—were pre-dried in an oven for 24 hours, and the NBR 7211 (ABNT, 2022) standard, which focuses on concrete aggregates, was adopted to evaluate the fine aggregates.

Before being used in the mixes, all aggregates were evaluated based on the following tests: granulometric composition, according to NBR NM 248 (ABNT, 2001); specific mass, using the Chapman Flask method; bulk density of the aggregate in loose and dry states, both according to NBR NM 45 (ABNT, 2006); content of powdery material, as per NBR NM 46 (ABNT, 2003); and determination of organic impurities, according to NBR NM 49 (ABNT, 2001).

In pursuit of the desired finish and to standardize the mixes, the aggregates were passed through sieves with an opening of 2.8 mm to standardize the maximum diameter and remove impurities. Physically different, Figure 1 shows the natural sand compared to the vermiculite after sieving.

Figure 1 – Natural sand on the left and vermiculite on the right

Source: authors (2024).

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The mortars were produced using a 1:1:6 (cement:lime) volumetric mix based on the theoretical framework (Carasek, 1996 and Barros, 2018). Sand was replaced with expanded vermiculite at 10% (VE10) and 20% (VE20) to compare with a reference mortar without substitution (AN100). In the fresh state, the mixtures underwent the mass density test in accordance with NBR 13278 (ABNT, 2005).

For the evaluation of the mortars in the hardened state, specimens for each mix were cast. The prismatic molds of 40 x 40 x 160 mm were demolded after 24 hours and then stored under ambient temperature and humidity conditions in the laboratory (Figure 2).

According to NBR 13279 (ABNT, 2005), the flexural tensile strength test was performed on specimens aged 28 days. For the test, the specimens were placed in the supports of the testing equipment such that the smoothed face did not come into contact with the supports or the load device. Then, a load of (50 ± 10) N/s was applied until the specimen failed (Figure 3).

Figure 2 – Test specimens of 40 x 40 x 160 mm

Source: authors (2024).

Figure 3 – Flexural tensile strength test

Source: authors (2024).

4 RESULTS

The physical properties of the natural sand and expanded vermiculite aggregates are presented in Table 1.

Table 1 – Physical properties of aggregates

Property	Natural sand	Expanded vemiculite
Maximum dimension (mm)	1,2	2,4
Fineness modulus (mm)	1,78	2,87
Specific mass (g/cm³)	1,68	0,63
Unit mass (g/cm³)	1,59	0,18

Source: authors (2024).

For the preparation of the mortars, the quantity of components in each mix was determined through the analysis of the granulometric curves. In the granulometric

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characterization of the sand and expanded vermiculite, performed according to NBR 7211 (ABNT, 2022), most of the aggregates were concentrated in the usable zone.

According to NBR 13276 (ABNT, 2016), in the absence of data, the amount of water in the mix should ensure a consistency index of 260 ± 10 mm. Thus, the water content for each mix was determined based on the consistency index test.

For the reference mortar (AN100), a water/cement ratio of 1.44 was found, which was maintained for VE10 and VE20 to ensure the workability of the mixes. Thus, the amount of water was adjusted in the mixes containing vermiculite to achieve the consistency index of 260 ± 10 mm recommended by the standard. A plasticizer additive was also used to improve the workability of the mortars, following the manufacturer's recommendation of 2 ml of additive per 1.0 kg of cement. Table 2 presents the final consumption of each component in the mixes.

Table 2 – Final consumption of mixture components

Mix	Cement (kg)	Lime (kg)	Sand (kg)	Vermiculite (kg)	Water (kg)	Plasticizing aditive (ml)
AN100	5,00	3,08	39,92	0	7,24	10
VE10	5,00	3,08	35,93	0,45	7,24	11
VE20	6,25	3,08	31,94	0,90	9,05	12

Source: authors, 2024.

Regarding the binders, the specific mass values (real and unit) provided by the manufacturers for the cement and lime were used to convert the mixes into mass proportions (Guilherme, 2019; Guilherme, Cabral, and Souza, 2020). The mixes in volume and mass are presented in Table 3.

Table 3 - Mixes in volume and mass

Mix	Substitution content	Mix in volume	Mix in mass	Water/cement ratio
AN100	0%	1:1:6:0	5:3,1:39,92:0	1,44
VE10	10%	1:1:5,4:0,6	5:3,1:35,92:0,45	1,44
VE20	20%	1:1:4,8:1,2	5:3,1:31,93:0,90	1,44

Source: authors, 2024.

After the preparation of the mixes, the characterization of the mortars in the fresh state was carried out through the mass density and consistency index tests, performed according to NBR 13276 (ABNT, 2016), which recommends a consistency index of 260 ± 10 mm.

Using the Flow Table method, the fresh state bulk density test was performed for the reference mix (AN100), and the average obtained was 257.85 mm. The water/cement ratio found was 1.44, and the same proportion was maintained for the other mixtures to ensure their workability. Table 4 summarizes the results obtained in the tests of the fresh state mortars.

Table 4 – Properties of mortars in the fresh state

Mix	Water/cement ratio	Mass density (kg/m³)	Consistency index (mm)
AN100	1,44	1840	257,85
VE10	1,44	1990	250,64
VE20	1,44	1980	252,02

Source: authors, 2024.

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The observation of the results obtained in the fresh state tests shows that, compared to the reference mix, the mixtures with vermiculite had higher bulk density values. There was an increase in bulk density in the VE10 mix (1990 kg/m³), followed by a slight decrease in VE20 (1980 kg/m³), both of which are higher than the value found for AN100 (1840 kg/m³).

In the case of the consistency index, all values were lower in the mixtures with vermiculite. Considering the mix without substitution, the consistency index decreased in VE10 (250.64 mm) and, even though it increased slightly in VE20 (252.02 mm), neither reached the value of AN100 (257.85 mm).

The NBR 13279 (ABNT, 2005) standard establishes that at least three specimens, aged 28 days, must be used in the flexural tensile strength test. In this research, most tests were carried out with a minimum of six specimens for each mix, which particularly allowed for the observation of the coefficient of variation. The results obtained from the flexural tensile strength test for the three mixes investigated in this study are presented in Table 5.

Table 5 – Flexural tensile strength (MPa) at 28 days

Test specimen	AN100	VE10	VE20
1	1,49	2,06	2,26
2	1,47	2,07	2,17
3	1,44	2,04	2,50
4	2,07	1,83	2,27
5	1,59	1,83	2,20
6	1,33	1,92	2,12
7	1,65	-	2,24
8	1,41	-	2,18
9	1,42	-	2,10
10	1,73	-	2,39
11	1,34	-	2,28
12	1,36	-	2,09
Mean (MPa)	**1,53**	**1,96**	**2,23**
Standard deviation	**0,21**	**0,11**	**0,12**
Coefficient of variation	**13,90**	**5,77**	**5,38**

Source: authors, 2024.

Thus, for the mixes studied in this research, the higher the replacement ratio of sand with expanded vermiculite, the greater the flexural tensile strength observed. The highest average was found in the mix with the highest amount of vermiculite (VE20), while the lowest was observed in the mix without replacement (AN100). These results, therefore, differ from those observed by Barros (2018), Sinhorelli (2019), Nascimento (2021), and Kaya and Köksal (2022), where vermiculite reduced the flexural tensile strength.

In Guilherme (2019), the results for flexural tensile strength were practically unchanged with the addition of vermiculite to the mixes. Since the values remained essentially constant and there was a slight reduction in the mix with 50% replacement of sand with vermiculite, the author concluded that vermiculite has little influence on this property. Similarly, in Fontes *et al*. (2022), the inclusion of expanded clay as an aggregate also resulted in similar flexural tensile strength values across all mortar samples.

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Similarly to the test conducted in this study, an increase in flexural tensile strength was also observed with the replacement of sand by rice husk straw in Akiniemy *et al*. (2020) and by mineral wool fibers in Ferrandéz *et al*. (2022).

Other aggregates resulted in lower values of flexural tensile strength when compared to the reference mortar without substitutions, such as: EPS residues in Passos and Carasek (2018), recycled tire rubber residues in Rocha (2019), mineral wool fibers in Awoyera *et al*. (2022), PVC and rubber residues in El-Seidy *et al*. (2022), and polystyrene fibers in Ferrandéz *et al*. (2022).

5 CONCLUSION

In observing the results of the fresh state tests, the bulk density was higher in all mixtures with expanded vermiculite. Compared to the reference mix, there was an increase in bulk density in the fresh state for VE10, followed by a slight reduction in the VE20 mix, with both being higher than the density of AN100. For the consistency index, all values observed for the mixes incorporating vermiculite were lower than that of AN100, the reference mix.

Thus, the results allowed us to infer that as the substitution of sand by expanded vermiculite increased, the tensile strength in flexion of the mortars compared to the reference mix improved. In this scenario, all the mixes with expanded vermiculite (VE10 and VE20) showed higher mechanical strength compared to AN100.

Therefore, as the inclusion of vermiculite in these proportions did not significantly compromise the performance of the mixes, the analysis allowed for the recommendation of these mixes for use as plastering mortars.

BIBLIOGRAPHICAL REFERENCE

AKINYEMI, Banjo; OMONIYI, Temidayo E.; ELEMILE, Olugbenga; AROWOFILA, Oluwafemi. Innovative Husk-Crete Building Materials from Rice Chaff and Modified Cement Mortars. **Acta Technologica Agriculturae**, v. 23, n. 2, p. 67-72, 2020. Disponível em: http://dx.doi.org/10.2478/ata-2020-0011. Acesso em: 15 ago. 2024.

ASSOCIAÇÃO BRASILEIRA DE NORMAS TÉCNICAS. **ABNT NBR 7200**: execução de revestimento de paredes e tetos de argamassas inorgânicas – procedimento. Rio de Janeiro, ABNT, 1998.

ABNT. **ABNT NBR NM 45**: agregados - determinação da massa unitária e do volume de vazios. Rio de Janeiro, ABNT, 2006.

_____. **ABNT NBR NM 46**: agregados - determinação do material fino que passa através da peneira 75 um, por lavagem. Rio de Janeiro, ABNT, 2003.

_____. **ABNT NBR NM 49**: agregado miúdo - determinação de impurezas orgânicas. Rio de Janeiro, ABNT, 2001.

_____. **ABNT NBR NM 248**: agregados - determinação da composição granulométrica. Rio de Janeiro, ABNT, 2001.

_____. **ABNT NBR 13278**: argamassa para assentamento e revestimento de paredes e tetos - determinação da densidade de massa e do teor de ar incorporado. Rio de Janeiro, ABNT, 2005.

_____. **ABNT NBR 13279**: argamassa para assentamento e revestimento de paredes e tetos – determinação da resistência à tração na flexão e à compressão. Rio de Janeiro, ABNT, 2005.

AWOYERA, Paul O.; AKINRINADE, Ayomide D.; GALDINO, André Gustavo de Sousa; ALTHOEY, Fadi; KIRGIZ, Mehmet Serkan; TAYEH, Bassam A. Thermal insulation and mechanical characteristics of cement mortar reinforced with mineral wool and rice straw fibers. **Journal of Building Engineering**, v. 53, p. 104568, 2022. Elsevier BV. Disponível em: http://dx.doi.org/10.1016/j.jobe.2022.104568. Acesso em: 16 ago. 2024.

BARROS, Ilana Maria da Silva. **Análise térmica e mecânica de argamassas de revestimento com adição de vermiculita expandida em substituição ao agregado**. 2018. Dissertação (mestrado em Engenharia Civil) – Centro de Tecnologia, Universidade Federal do Rio Grande de Norte, Natal, RN, 2018. Disponível em: https://repositorio.ufrn.br/handle/123456789/25165. Acesso em: 10 jul. 2024.

EL-SEIDY, Eslam; SAMBUCCI, Matteo; CHOUGAN, Mehdi; AL-KHEETAN, Mazen J.; BIBLIOTECA, Ilario; VALENTE, Marco; GHAFFAR, Seyed Hamidreza. Mechanical and physical characteristics of alkali- activated mortars incorporated with recycled polyvinyl chloride and rubber aggregates. **Journal of Building Engineering**, v. 60, p. 105043, 2022. Elsevier BV. Disponível em: http://dx.doi.org/10.1016/j.jobe.2022.105043. Acesso em: 13 ago. 2024.

FERRÁNDEZ, Daniel; YEDRA, Engerst; MORÓN, Carlos; ZARAGOZA, Alicia; KOSIOR-KAZBERUK, Marta. Circular Building Process: reuse of insulators from construction and demolition waste to produce lime mortars. **Buildings**, v. 12, n. 2, p. 220, 2022. Disponível em: http://dx.doi.org/10.3390/buildings12020220. Acesso em: 10 ago. 2024.

FONTES, Adna Érica Melo de Sousa; CABRAL, Kleber Cavalcanti; SOUZA, Wendell Rossine Medeiros de; MARTINELLI, Antônio Eduardo; FONTES, Kristy Emanuel Silva. Análise mecânica e térmica de argamassas de revestimento com substituição parcial do agregado por ar. **Ambiente Construído**, v. 22, n. 3, p. 299-311, 2022. Disponível em: http://dx.doi.org/10.1590/s1678-86212022000300620. Acesso em: 14 ago. 2024.

GUILHERME, Deize Daiane Pinto. **Estudo do desempenho térmico e mecânico em argamassas de revestimento com substituição do agregado natural pela vermiculita expandida**. 2019. Dissertação (mestrado em Engenharia Civil) – Centro de Tecnologia, Universidade Federal do Rio Grande de Norte, Natal, RN, 2019. Disponível em: https://repositorio.ufrn.br/jspui/handle/123456789/28547. Acesso em: 7 jul. 2024.

KAYA, Mehmet; KÖKSAL, Fuat. Physical and mechanical properties of C class fly ash based lightweight geopolymer mortar produced with expanded vermiculite aggregate. **Revista de la Construcción**, v. 21, n. 1, p. 21-35, 2022. Pontificia Universidad Catolica de Chile. Disponível em: http://dx.doi.org/10.7764/rdlc.21.1.21. Acesso em: 7 ago. 2024.

NASCIMENTO, Raquel Ferreira do. **Efeito da hidroxipropilmetilcelulose em argamassas leves térmicas à base de vermiculita expandida**. 2021. Dissertação (mestrado em Engenharia Civil) – Centro de Tecnologia, Universidade Federal do Rio Grande de Norte, Natal, RN, 2021. Disponível em: https://repositorio.ufrn.br/handle/123456789/45248. Acesso em: 13 ago. 2024.

PASSOS, Paulo Martins dos; CARASEK, Helena. Argamassas com resíduos para revestimento isolante térmico de parede pré-moldada de concreto. **Cerâmica**, v. 64, n. 372, p. 577-588, 2018. Disponível em: http://dx.doi.org/10.1590/0366-69132018643722391. Acesso em: 5 ago. 2024.

ROCHA, Vicente de Paula Teixeira. **Desenvolvimento de argamassas para revestimento de alvenaria com adição de borracha reciclada de pneu**. 2019. Tese (doutorado em Engenharia Agrícola) - Centro de Tecnologia e Recursos Naturais, Universidade Federal de Campina Grande, Campina Grande, PB, 2019. Disponível em: http://dspace.sti.ufcg.edu.br:8080/jspui/handle/riufcg/35621. Acesso em: 10 jul. 2024.

SILVA, Jussara Adílio da; PIVA, Jorge Henrique; WANDERLIND, Augusto; SAVI, Aline Eyng; ANTUNES, Elaine Guglielmi Pavei. Análise das características físicas e propriedades mecânicas de argamassa com inserção de resíduos de

ISSN 2318-8472, v. 12, n. 87, 2024

madeira. **Matéria (Rio de Janeiro)**, v. 26, n. 3, p. 1-11, 2021. Disponível em: http://dx.doi.org/10.1590/s1517-707620210003.13008. Acesso em: 15 ago. 2024.

SINHORELLI, Kássia dos Santos. **Estudo das propriedades reológicas e térmicas das argamassas de revestimento contendo adições minerais e vermiculita**. 2019. Dissertação (mestrado em Engenharia Civil e Ambiental) – Centro de Tecnologia, Universidade Federal da Paraíba, João Pessoa, PB, 2019. Disponível em: https://repositorio.ufpb.br/jspui/handle/123456789/19802?locale=pt_BR. Acesso em: 16 jun. 2024.

ZÁLESKÁ, Martina; PAVLÍKOVÁ, Milena; VYŁVAřIL, Martin; PAVLÍK, Zbyšek. Effect of Aggregate and Binder Type on the Functional and Durability Parameters of Lightweight Repair Mortars. **Sustainability**, v. 13, n. 21, p. 11780, 2021. Disponível em: http://dx.doi.org/10.3390/su132111780. Acesso em: 6 ago. 2024.