RECTANGULAR CONCRETE BLOCKS FOR INTERLOCKING PAVING: USE OF SPENT FOUNDRY SAND AS A SUBSTITUTE FOR NATURAL SAND

BLOCOS DE CONCRETO RETANGULARES PARA PAVIMENTAÇÃO INTERTRAVADA: USO DE AREIA DESCARTADA DE FUNDIÇÃO COMO SUBSTITUTO DA AREIA NATURAL

BLOQUES RECTANGULARES DE HORMIGÓN PARA PAVIMENTOS ENTRELAZADOS: UTILIZACIÓN DE ARENA DE FUNDICIÓN USADA COMO SUSTITUTO DE LA ARENANATURAL

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ABSTRACT
The foundry industry generates large quantities of spent foundry sand (SFS), a solid waste. The use of SFS as a substitute for natural sand is a more sustainable solution to address disposal issues. In this study, rectangular concrete blocks were developed for use in paving with total replacement of natural sand by SFS contaminated with phenolic resins. This allowed for an analysis of the influence of SFS on concrete properties. The SFS was characterized using X-ray diffraction, X-ray fluorescence, thermal analysis, and scanning electron microscopy. The blocks' mechanical and chemical properties demonstrate their technical feasibility and compliance with Brazilian pavement application regulations (compression strength > 50 MPa and water absorption < 6%). Therefore, this study suggests that producing rectangular concrete blocks with total sand replacement with SFS is a more sustainable, technically and economically feasible alternative.

KEYWORDS
Spent Foundry Sand; Concrete Blocks; Phenolic Resin; Waste Foundry Sand; Interlocked Pavement

RESUMO
A indústria de fundição gera grandes quantidades de resíduo de areia descartada de fundição (ADF). O uso de ADF como substituto da areia natural é uma solução mais sustentável para resolver problemas de descarte. Neste estudo, blocos retangulares de concreto foram desenvolvidos para uso em pavimentação com substituição total de areia natural por ADF contaminada com resinas fenólicas. Isso permitiu uma análise da influência do ADF nas propriedades do concreto. O ADF foi caracterizado usando difração de raios X, fluorescência de raios X, análise térmica e microscopia eletrônica de varredura. As propriedades mecânicas e químicas dos blocos demonstram sua viabilidade técnica e conformidade com as regulamentações brasileiras de aplicação de pavimentos (resistência à compressão > 50 MPa e absorção de água < 6%). Portanto, este estudo sugere que a produção de blocos retangulares de concreto com substituição total de areia por ADF é uma alternativa mais sustentável, técnica e economicamente viável.

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PALAVRAS-CHAVE
Areia descartada de fundição; Blocos de concreto; Resina fenólica; Areia de fundição residual; Pavimento intertravado

RESUMEN
La arena de fundición gastada (AFG) es un residuo sólido generado en grandes cantidades por la industria de fundición. El uso de AFG como sustituto de la arena natural representa una solución más sostenible para abordar los problemas de disposición. En este estudio, se desarrollaron bloques de concreto rectangulares para su uso en pavimentación, reemplazando totalmente la arena natural por AFG contaminada con resinas fenólicas. Esto permitió analizar la influencia de la AFG en las propiedades del concreto. La AFG fue caracterizada mediante Difracción de Rayos X y Fluorescencia de Rayos X, análisis térmico y Microscopía Electrónica de Barrido. Las propiedades mecánicas y químicas de los bloques obtenidos demuestran su viabilidad técnica y conformidad con las normas reglamentarias brasileñas para aplicaciones en pavimentos (resistencia a la compresión > 50 MPa y absorción de agua < 6%). Por lo tanto, este estudio sugiere que la producción de bloques de concreto rectangulares con reemplazo total de arena por AFG es una alternativa más sostenible, técnica y económicamente viable.

PALABRAS CLAVE
Arena de fundición gastada; Bloques de hormigón; Resina fenólica; Arena residual de fundición; Pavimento entrelazado

1. INTRODUCTION

A country's industrial development closely links the steel industry and melting processes, which involve activities in the automotive, domestic, military, and agro-industrial sectors (CHEGATTI, 2016; MURARI; SIDDIQUE; JAIN, 2015). Smelters, in particular, are significant contributors to gas emissions and solid waste generation, including spent foundry sand (SFS) and slag. The production of molten metal generates approximately 0.8 to 1.0 kilograms of waste foundry sand (WFS). This indicates a direct correlation between production volumes and waste generation. In 2020, the global production of solid foundry waste was approximately 105.5 million metric tons, highlighting the extensive scale of waste associated with these industrial processes (SRD, 2022).

This work aims to establish a methodology in accordance with the Brazilian Association of Technical Standards (ABNT) — Standard NBR 9781 (NBR 9781, 2013) – to determine the technical feasibility of reusing SFS contaminated with phenolic resin as a replacement for natural sand in the production of rectangular concrete blocks for paving. Furthermore, only a small number of papers have investigated the use of SFS as a recyclable component in paving block production. This area is of significant interest to both materials researchers and environmental engineers due to the potential for interdisciplinary collaboration focused on sustainable practices.

2. LITERATURE REVIEW

Waste foundry sand that contains physical binders exhibits a significant variation in its silicon dioxide (SiO_2) content, ranging from 78.4% to 94.1%. This variability in composition can result in different properties, which makes it challenging to use in various applications (PAIVA *et al.*, 2021). On the other hand, the use of phenolic resin as a chemical binder in the preparation of sand molds to produce metallic components results in WFS with high SiO_2 concentrations, up to 99%. While this high concentration of SiO_2 makes results more predictable and makes WFS better for mixing with cementitious materials, it opens up a wider range of possible uses (MAVROULIDOU; LAWRENCE, 2019; SANTOS *et al.*, 2021).

Guerino *et al.* (GUERINO, K.B; VICENZI, J; BRAGANÇA, S.R; BERGMANN, 2010) (NBR 10004, 2004; NBR 10005:2004, 2004; NBR 10006:2004, 2004) evaluated and classified the specimens as inert materials. Due to their high concentration of silicon dioxide (SiO_2), these SFS reuses can also serve as raw materials for the production of glasses and glass-ceramic materials. Silva *et al.* (SILVA *et al.*, 2020) were able to replace 100% of the silica by SFS for the production of this type of material.

Paiva *et al.* (DE PAIVA *et al.*, 2023) produced mortars with up to 50% waste foundry phenolic sand (WFPS), which has a high concentration of phenolic resin on its surface. The study found that high concentrations of resin significantly increase the void index, reducing the mechanical strength of cementitious composites. The authors (DE PAIVA *et al.*, 2023) attribute this low interfacial interaction to the WFPS and the cement matrix. Mastella *et al.* (MASTELLA *et al.*, 2014) investigated the impact of substituting traditional sand with resin-contaminated waste foundry sand in the composition of concrete blocks. The WFS underwent thermogravimetric analysis, which revealed a minimal mass loss of 0.9% within the temperature range of 400 to 450 °C, attributed to the presence of resin. The study found that replacing up to 25% of conventional sand by WFS does not negatively impact the mechanical strength of concrete. This was observed at hydration intervals of 28, 56, and 91 days. Also, Fourier-transform infrared (FTIR) spectroscopy of the WFS revealed an aliphatic structure, which is different from what is usually seen for phenols, which have a carboxylic acid structure. This suggests that formaldehyde is present. The compound's low water solubility suggests minimal environmental impact, as it results in negligible leaching (MASTELLA *et al.*, 2014).

Under Brazilian law, smelters must dispose of their SFS in licensed landfills. However, due to the limited number of available landfills, service providers charge high fees for transporting residues from industries to the final destination. This results in many companies resorting to unauthorized disposal methods, which are illegal and harmful to the environment (ABIFA, 2008).

Generally, the molds used in the foundry industries are formed by silica sand mixed with a binder (phenolic resin, bentonite clay, coal powder, and carbonaceous material) and water. In a previous publication, SANTOS *et al.* (2021) presented the characterization of spent foundry sand mixtures (SFS-M), incorporating several different binders, and explored their novel application in the production of concrete blocks for interlocking pavements.

In 2021, Santos *et al.* carefully collected WFS from five different industrial sources. They divided the samples into two groups based on the type of binder they were: chemical and physical. Two of the chemical binder samples were mixed with three of the physical binder samples and then used in interlocking concrete blocks (SANTOS *et* *al.*, 2021). A scanning electron microscope (SEM) analysis showed that the surface of WFS had small particles. These particles were made up of compounds like bentonite, coal dust, and phenolic resin. Concrete samples containing 100% WFS in place of sand showed a reduction in mechanical strength of up to 50%. The presence of surface impurities correlated this reduction with impaired interfacial adhesion between WFS and the cement matrix. This observation, documented by Santos *et al.* (2021), underscores the critical impact of surface cleanliness on the mechanical performance of concrete composites containing WFS.

3. MATERIALS AND METHODS

3.1 Natural Sand and Spent Foundry Sand

The physical and chemical properties of Natural Sand and SFS were compared through characterization. Natural sand is commonly used in the construction and building industry for concrete production. SFS, contaminated with phenolic resins, was collected from a smelter in Presidente Prudente, São Paulo, Brazil, that produces white, gray, and nodular cast iron.

3.2 Sand Caracterization

Approximate values for the most stable oxide percentages of Natural Sand and SFS were obtained using an energy dispersive X-Ray Fluorescence spectrometer (EDX7000, Shimadzu) with Rh atoms as the primary radiation. We analyzed the scanning from Na to U in the qualitative-quantitative mode, keeping the temperature and pressure at normal. We used a biaxially-oriented polyethylene terephthalate (boPET, Mylar®) sample holder. We found the crystalline phases of all the synthesized samples using X-ray diffractometry (XRD) on an X-ray diffractometer (XRD-6000, Shimadzu) with Cu K±1 (λ = 1.5406 Å) and Cu K±2 (λ = 1.5444 ô) radiation. The divergence and reception slits were set to 1º in continuous scan mode, with a 40 kV voltage, 30 mA current, 2º/min scan speed, and 2θ angular range from 10º to 80º. The diffraction spectra were identified using the crystallographic records from the Powder Diffraction Files (PDF) of the Joint Committee on Powder Diffraction Standards—International Center for Diffraction Data (JCPDS-ICDD) database.

Thermal analysis was performed using a SDT Q600 instrument from TA Instruments to identify thermal degradation and phase transformations. We analyzed the sands in alumina crucibles, maintaining a heating rate of 10 oC/min, an equilibrium temperature of 30 oC, and a synthetic air atmosphere with a flow rate of 100 mL/min. The maximum temperature was 1000 ºC. We evaluated the SFS morphology using Scanning Electron Microscopy (SEM) with an EVO LS 15 instrument from Zeiss. A Q150TE instrument from Quorum used an evaporation process to coat the sample with gold.

The natural sand and SFS were tested for bulk specific gravity using ABNT Standard NBR 9781 (NBR 9781, 2013). Granulometric analysis was conducted following ABNT Standard NBR (NBR 248, 2003). The classification of the samples within the recommended granulometric range (optimal and usable zones) was determined through visual analysis, in accordance with ABNT Standard NBR 7211 (NBR 7211, 2022).

3.3 Production of Rectangular Concrete Blocks

Two traces were prepared: one for reference (natural sand) and the other for SFS. The only difference between them is the total replacement of the natural thin aggregate with SFS, as shown in **Table 1**. The composition of the Reference trace was performed in accordance with the trace used in the industrial sector (SIDDIQUE *et al.*, 2015).

Constituents	Reference Trace	SFS Trace
Cement (kg/m³)	288.0	288.0
Natural Sand (kg/m³)	330.0	-
SFS* (kg/m³)	-	326.7
Fine Gravel (kg/m³)	565.3	565.3
Water (kg/m³)	94.2	94.2
Additive (kg/m³) – 0.05% Cement	1.44	1.44
Slump Test	0	0

SFS* - SFS with phenolic resins

Table 1: Concrete mix proportions.

Source: authors.

In this work, we used High Initial Strength (HIS) cement, with a water/cement ratio of 94.2 kg/m³ for both mixes.

Following ABNT Standard NBR 9781 (NBR 9781, 2013), we produced ten rectangular concrete blocks (8 x 15 x 25 cm—**Figure 1**) using both the reference and SFS traces. The concrete mixer in use had a capacity of 100 liters. The order of placement in the mixer is crucial: begin with the addition of fine gravel (coarse aggregate), followed by half the volume of water, HIS cement, natural sand (or SFS), the remaining volume of water, and finally the additive.

Figure 1: Shows some of the rectangular concrete blocks produced by SFS trace, with dimensions of 8 x 15 x 25 cm.
Source: authors.

The concrete compositions were mixed for 5 minutes and then subjected to the trunk abatement test, according to ABNT – Standard NBR NM 67 (NM 67, 1998). Next, the rectangular concrete blocks were shaped into molds containing lubricating oil to facilitate immediate deformation, as per ABNT – Standard NBR 5739 (NBR 5739, 2018). Next, we vibrated the molds on a vibrating table for approximately 15 seconds before unmolding them onto a clean, flat surface.

The curing process was carried out in a moist chamber. We maintained the healing period until the rupture ages, which were 7 and 28 days. To conduct the compressive strength tests, it was necessary to flatten the concrete blocks' surfaces to ensure homogeneous distribution of the applied force during the test. We performed the flattening procedure for the rectangular concrete blocks using a cement paste in accordance with ABNT-Standard NBR 9781. The rectangular concrete blocks were subjected to tests for compressive strength and water absorption through immersion, in accordance with ABNT Standard NBR 9781.

The water absorption test results were calculated using the arithmetic mean value of five specimens (blocks made with natural sand and SFS) and Equation 1 from ABNT - Standard NBR 9778 (NBR 9778, 2009).

$$A = \left(\frac{m_2 - m_1}{m_1}\right) x100 \qquad \text{Equation 1}$$

In which A is the total water absorption (%), m^1 is the dried block (110 ± 5 °C) mass (g) and m^2 is the saturated block mass (g).

Compressive strength tests were conducted using a 20T universal testing machine (UTM). The results were calculated as the arithmetic mean of five rectangular concrete blocks made with natural sand and SFS).

The cross-section of rectangular concrete blocks (28 days) was analyzed using an optical microscope (V12 Stereo Discovery, Zeiss) coupled with a digital camera (SSC-DC54A, Sony).

4. RESULTS AND DISCUSSION

Table 2 shows the chemical composition of natural sand and SFS as determined by XRF spectroscopy. The casting process, which uses sand as a refractory material to prepare molds to produce metallic pieces, is characterized by the high content of silicon dioxide (SiO2). It is worth noting that the SFS sample has a higher concentration of SiO2 (98.311 wt%) than the commercial Natural Sand sample (91.462 wt%). During the casting process, small amounts of other metals present in the natural sand diffuse into the metal cast. Both samples contain SO3, which is related to the phenolic resins used in the molding process for SFS and to a common and small contamination present in natural sand. The minor concentration elements originate from scrap and refractory furnaces, as well as other mineralogical components (VARGAS *et al.*, 2015).

Constituents	Natural Sand	SFS
SiO_2	91.462	98.311
Al_2O_3	3.954	-
Fe_2O_3	1.082	0.562
TiO_2	0.927	-
SO_3	0.718	0.533
CaO	0.708	0.366
K2O	1.055	0.108
CuO	0.012	0.079
ZrO_2	-	0.033
ZnO	0.006	0.008
Other	0.076	-

Table 2: Chemical composition of Natural Sand and SFS by XRF spectroscopy.
Source: authors.

Figure 2 (a) and **Figure 2 (b)** show the XRD patterns for natural sand and SFS, respectively. The test showed that alpha quartz (α-SiO_2) was the only crystalline phase (PDF 5–490) in both samples, which matches the results

177

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of the XRF analysis. The darker color of SFS (inset (b) in Figure 2) compared to Natural Sand (inset (a) in Figure 2) might be because it has phenolic resins in it, since neither bentonite nor coal powder were added to this SFS.

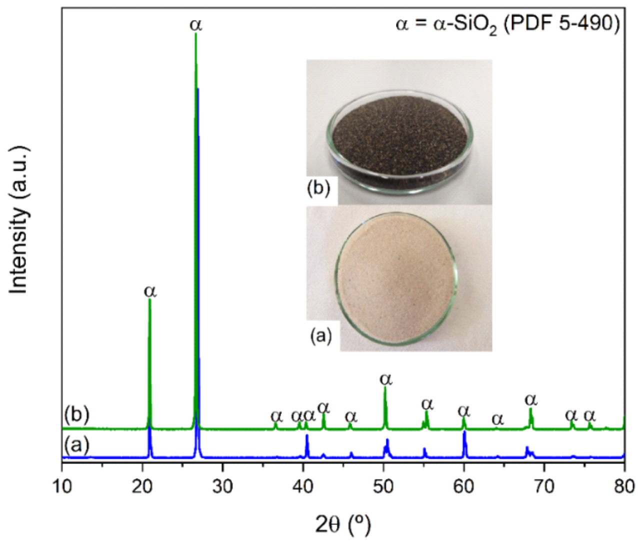

Figure 2: DRX patterns of (a) Natural Sand and (b) SFS. Inset: digital image of (a) Natural Sand and (b) SFS.
Source: authors.

Figure 3 (a) and **(b)** display the thermal analyses for natural sand and SFS, respectively. The analysis for natural sand reveals a single endothermic reaction at approximately 572 ºC, which corresponds to the polymorphic transition of quartz (α-SiO_2 to β-SiO_2) (PEREIRA *et al.*, 2014). The weight fluctuations observed in this sample's thermogravimetric curve are likely due to background noise rather than real reactions. The weight values only vary slightly, from 30.20 to 30.25 mg, which is close to the equipment limit.

The thermogravimetry analysis data from SFS shows that the first thermal event occurs in a range from ambient temperature to approximately 100°C and is related to the loss of adsorbed water (moisture). The second thermal event starts after 200°C (calibration temperature of the DSC equipment) and extends up to 850°C. The loss of about 0.30 mg of mass from the phenolic resins that formed around the grains of SFS is due to the raw materials used in the molding process and/or Macharia (CARNIN *et al.*, 2012). The differential scanning calorimetry data shows an endothermic peak at 572 ºC. This is because α-SiO_2 changes to β-SiO_2, which we already talked about.

Figure 4 presents SEM micrographs of the SFS, magnified at 100x, 300x, and 350x. The images show that the heterogeneous grains of the SFS have irregular surfaces and varying sizes. Additionally, layers of phenolic resins can be observed surrounding the SFS grains (ZHANG *et al.*, 2013).

The analysis of bulk specific gravity yielded a value of 2.85 g/cm^3 for natural sand and 2.65 g/cm2 for SFS. The production processes involving high temperatures and phenolic resins are responsible for the lower specific mass value of SFS. This reduction, however, has a positive impact on the final product, as blocks made with SFS are 7% lighter than those made with natural sand (reference blocks).

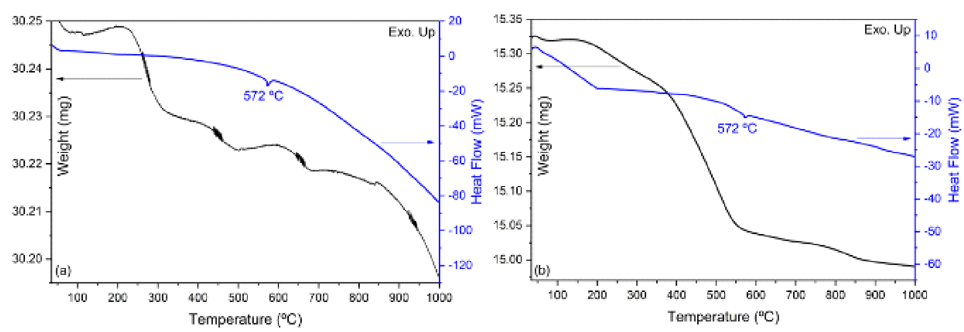

Figure 4: Thermogravimetry and differential scanning calorimetry analysis of (a) Natural Sand and (b) SFS.

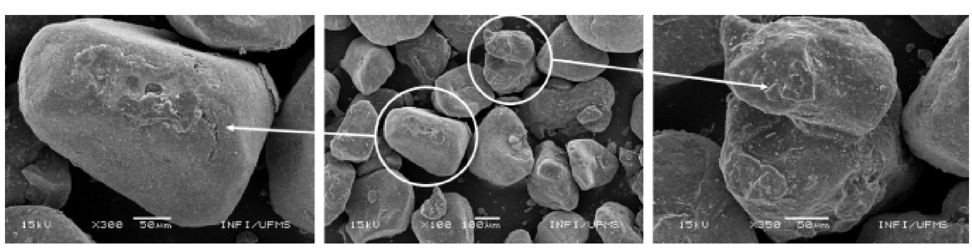

Figure 3: SEM images of SFS in 100x, 300x and 350x magnification.
Source: authors.

There was a problem with the granulometric curves of natural sand and SFS not fitting into the Usable Zone Optimum (UZO) set by ABNT-Standard NBR 7211. This can be seen in **Figure 5**. However, all grain sizes fall within the Usable Zone Limits (UZL) set by the same standard. Based on this analysis, we classified SFS as a usable and suitable fine aggregate for the concrete mix. We observed a reduction in grain diameters in the SFS compared to natural sand. The SFS has a higher percentage of smaller-diameter grains.

Figure 6 displays the individual and average results for the compressive strength of rectangular concrete blocks at 7 and 28 days of age for both reference and SFS traces. The axial compression strength of the rectangular concrete blocks after 7 days of curing in the wet chamber was 54.96 MPa for the reference trace and 53.30 MPa for the SFS trace. After 28 days of curing, the concrete blocks showed an increase in resistance. The reference trace had a mean value of 66.92 MPa, which represents a 21.76% increase, while the SFS trace had a mean value of 62.81 MPa, representing a 17.84% increase. According to ABNT - Standard NBR 9781 (NBR 9781, 2013), concrete blocks used for interlocked paving must have a minimum compressive strength of 35 MPa (for light trucks) and 50 MPa (for heavy trucks) (FORTES *et al.*, 2017). Therefore, the results obtained meet the standardized requirements satisfactorily. The blocks under study achieved high compressive strength on the 7th and 28th day due to the use of HIS cement in their production.

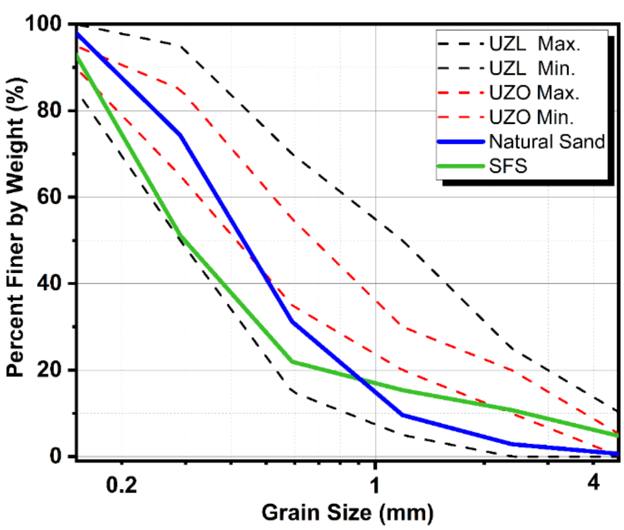

Figure 5: Granulometric curves of Natural Sand and SFS. The Usable Zone Optimum (UZO) and Usable Zone Limits (UZL) are shown.
Source: authors.

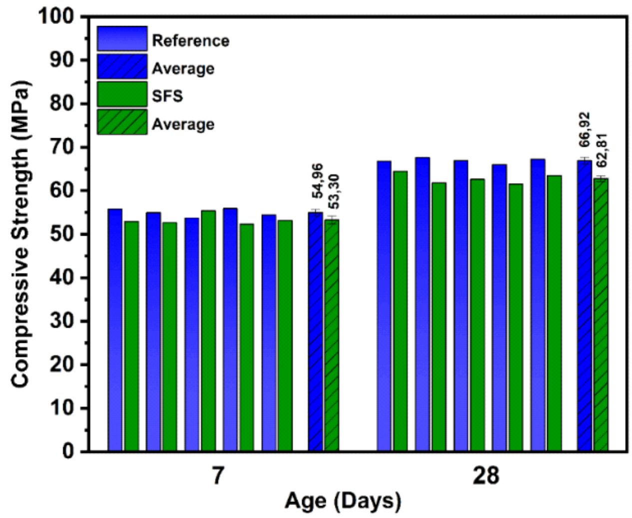

Figure 6: Individual and average values for the compressive strength of the rectangular concrete blocks.
Source: authors.

It was observed that the rectangular concrete blocks had a 6.14% reduction in compressive strength at 28 days of cure compared to the concrete blocks molded from the Reference trace, when the same proportion of materials in the trace (water, large aggregates, cement, and additive) were used, except for the small aggregate. The justification for this result is based on the fact that the SFS grains were coated with a phenolic resin, which resulted in a smaller particle size compared to the Natural Sand used in the Reference trace. These effects ultimately led to a reduction in compressive strength (AMITH; SABEEL, 2018).

Water absorption is influenced by sample compaction and curing conditions. **Figure 7** displays the individual and mean absorbance values of rectangular concrete blocks molded from the reference trace and the SFS trace. We obtained these values by conducting immersion absorption tests after 28 days. The immersion water absorption test results for the rectangular concrete blocks were 3.06% and 3.98% for the reference block and SFS trace, respectively. Both values are in accordance with the Brazilian standard (ABNT-Standard NBR 9781), which establishes a maximum average absorption of 6% for concrete pieces used in interlocking pavements. It is important to note that the amount of SFS used in this study for the concrete composition was 326.7 kg/m^3. If a higher amount of SFS is used, it may result in increased water absorption due to the presence of phenolic resins adhered to the SFS grains.

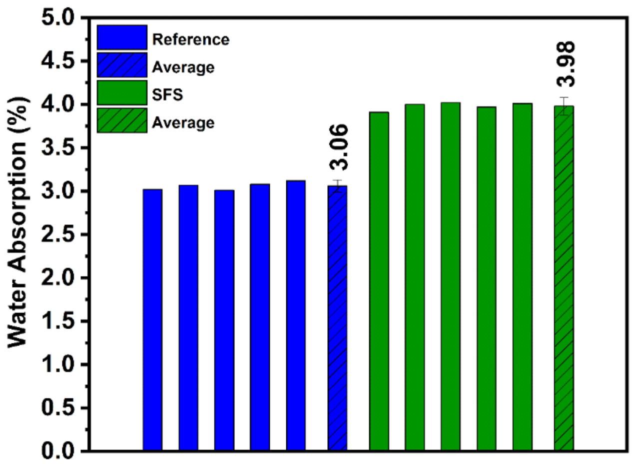

Figure 7: Individual and average values for the water absorpton of the rectangular concrete blocks.
Source: authors.

Optical microscopy aims to observe the surface and internal area of rectangular concrete blocks to understand the interaction between SFS, coarse aggregate, and cement. **Figure 8** shows an image of the internal area of the rectangular concrete block (80x). The micrograph of the internal sand of the rectangular concrete block shows homogeneity between the grains of SFS, which is an important feature for increasing compressive strength (DUERAMAE *et al.*, 2019). The sand contains large aggregates and cement. The SFS grains have rounded shapes, while other grains have a sub-angular format.

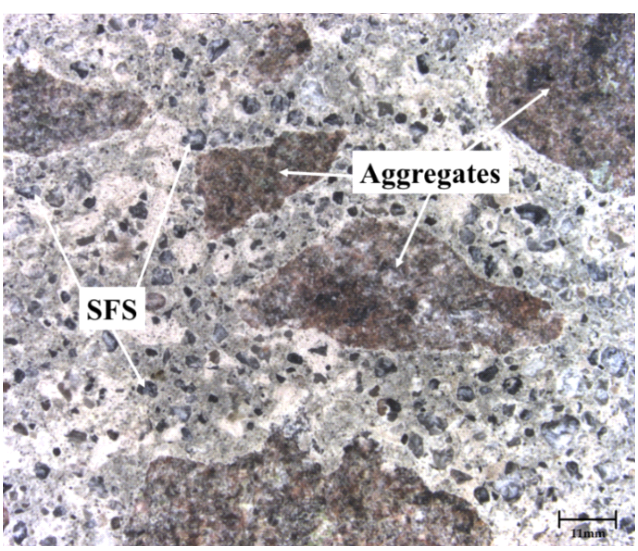

Figure 8: Photomicrograph of the rectangular concrete block (SFS trace). Nominal magnification at 80x.
Source: authors.

5. CONCLUSIONS

This study concludes that rectangular concrete blocks composed of SFS with phenolic resins exhibit a high concentration of silicon oxide (SiO_2), with quartz serving as the main phase. Scanning electron microscope (SEM) images of the blocks show layers of phenolic resins around the grains of silicon oxide, which has little effect on the blocks' properties. Additionally, the mechanical behavior of the blocks with SFS showed compression resistance above 50 MPa after 28 days, classifying them as concrete blocks suitable for heavy vehicles. The results show that it is possible to completely replace natural sand with SFS that has been contaminated with phenolic resins. This would produce a material with a compression strength of over 50 MPa and a water absorption rate of less than 6%, which is in line with Brazilian standards. The use of contaminated SFS with phenolic resins in concrete blocks offers technical, economic, and environmental advantages, considering the expenses associated with disposing of this solid residue in landfills.

REFERENCES

ABIFA, A. B. D. F. **Solutions for Spent Foundry Sand (SFS), Revista Fundição & Matérias-primas.** Disponível em: <http://abifa.org.br/wpcontent/uploads/2014/09/ABIFA-171-agosto.pdf>.

AMITH, K.; SABEEL, A. **Investigations on fly ash reinforced phenolic composite for green environment. Investigations on fly ash reinforced phenolic composite for green environment**, v. 9, n. 5, p. 27–31, 2018.

CARNIN, R. L. P. *et al.* Use of an integrated approach to characterize the physicochemical properties of foundry green sands. **Thermochimica Acta**, v. 543, p. 150–155, set. 2012.

CHEGATTI, S. **Spent Foundry Sand: Context, Management and Impact (In Portuguese)**. 1 rd ed ed. Curitiba, Brazil: [s.n.].

DE PAIVA, F. F. G. *et al.* Effect of phenolic resin content in waste foundry sand on mechanical properties of cement mortars and leaching of phenols behaviour. **Sustainable Chemistry and Pharmacy**, v. 31, p. 100955, abr. 2023.

DUERAMAE, S. *et al.* Investigation of compressive strength and microstructures of activated cement free binder from fly ash - calcium carbide residue mixture. **Journal of Materials Research and Technology**, v. 8, n. 5, p. 4757–4765, set. 2019.

FORTES, E. S. *et al.* Compressive strength of masonry constructed with high strength concrete blocks. **Revista IBRACON de Estruturas e Materiais,** v. 10, n. 6, p. 1273–1319, nov. 2017.

GUERINO, K.B; VICENZI, J; BRAGANÇA, S.R; BERGMANN, C. P. Use of foundry sand as raw material for the production of white triaxial ceramic. **Cerâmica Industrial**, v. 15, n. 4, p. 42–46, 2010.

MASTELLA, M. A. *et al.* Mechanical and toxicological evaluation of concrete artifacts containing waste foundry sand. **Waste Management**, v. 34, n. 8, p. 1495–1500, ago. 2014.

MAVROULIDOU, M.; LAWRENCE, D. Can waste foundry sand fully replace structural concrete sand? **Journal of Material Cycles and Waste Management**, v. 21, n. 3, p. 594–605, 19 maio 2019.

MURARI, K.; SIDDIQUE, R.; JAIN, K. K. Use of waste copper slag, a sustainable material. **Journal of Material Cycles and Waste Management**, v. 17, n. 1, p. 13–26, 3 jan. 2015.

NBR-248. Agregados-Determinação da composição granulométrica. **Nbr 248**, p. 6, 2003.

NBR 10004. Solid waste – Classification. **ABNT - Associação Brasileira de Normas Técnicas**, p. 1–71, 2004.

NBR 10005:2004. procedure for obtention leaching extract of solid wastes. **ABNT - Associação Brasileira de Normas Técnicas**, p. 1–16, 2004.

NBR 10006:2004. procedure for obtention of solubilized extraction of solid wastes **ABNT - Associação Brasileira de Normas Técnicas**. Rio de Janeiro, Brazil: [s.n.].

NBR 5739. **Concrete - Compression test of cylindrical specimens.** Rio de Janeiro, Brazil: [s.n.].

NBR 7211. **Aggregates for concrete - Specification.** Rio de Janeiro, Brazil: [s.n.].

NBR 9778. **Hardened mortar and concrete - Determination of absorption, voids and specific gravity.** Rio de Janeiro, Brazil: [s.n.].

NBR 9781. **Concrete paving units - Specification and test methods.** Rio de Janeiro, Brazil: [s.n.].

NM 67. **Concrete - Slump test for determination of the consistency.** Rio de Janeiro, Brazil: [s.n.].

PAIVA, F. F. G. DE *et al.* Utilization of inorganic solid wastes in cementitious materials – A systematic literature review. **Construction and Building Materials**, v. 285, p. 122833, 2021.

PEREIRA, A. H. A. *et al.* A study about the contribution of the α-β phase transition of quartz to thermal cycle damage of a refractory used in fluidized catalytic cracking units. **Cerâmica**, v. 60, n. 355, p. 449–456, set. 2014.

SANTOS, L. F. DOS F. DO. *et al.* Characterization and reuse of spent foundry sand in the production of concrete for interlocking pavement. **Journal of Building Engineering**, v. 36, p. 102098, 1 abr. 2021.

SIDDIQUE, R. *et al.* Comparative investigation on the influence of spent foundry sand as partial replacement of fine aggregates on the properties of two grades of concrete. **Construction and Building Materials**, v. 83, p. 216–222, 15 maio 2015.

SILVA, L. M. S. E *et al.* Utilization of discarded foundry sand (DFS) and inorganic waste from cellulose and paper industry for the manufacture of glass-ceramic materials. **Cerâmica**, v. 66, n. 380, p. 413–420, dez. 2020.

SRD. **Global casting production worldwide**, 2018 to 2020. Disponível em: <https://www.statista.com/statistics/237526/casting-production-worldwide-by-country/>.

VARGAS, A. S. DE *et al.* Geopolymeric mortars based on alkali-activated fly ash containing sand casting. **Cerâmica**, v. 61, n. 359, p. 317–322, set. 2015.

ZHANG, F. S. *et al.* A New-Type of Phenolic Resin Sand Control and its Construction Technology. **Advanced Materials Research**, v. 699, p. 83–86, maio 2013.

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LFS: conceptualization, formal analysis, invetsigation, methodology, visualization, writing - original draft and data curation.

FFGP: conceptualization, formal analysis, methodology, visualization and writing - review & editing.

WRPA: visualization and formal analysis.

AES: project administration and supervision.

SRT: project administration, funding acquisition, resources, writing - review & editing, conceptualization and supervision.

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