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Characterization of mortars with iron ore tailings using destructive and nondestructive tests

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HIGHLIGHTS

- IOTs have the potential to be used as a fine aggregate because they are relatively inert.
- The possibility of using IOTs in place of fine aggregate in the production of rendering mortars is a significant achievement.
- The mechanical wave propagation method is used to determine the mechanical properties of the resulting mortars.
- The determination of the static and dynamic Young's modulus of IOT mortars are presented using destructive and non-destructive tests.
- High-performance mortars can be produced not only as rendering material but also as structural material in building construction.

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ABSTRACT

Although several researchers have been working on the mechanical and physical characterization of iron-ore tailings (IOT) in order to consider the possibility of using this material to replace natural aggregate in the preparation of mortars, they have not investigated the dynamic and static modulus of elasticity of IOT mortars yet. Therefore, the main goal of this study is to present an experimental investigation on the determination of the static and dynamic Young's modulus of IOT mortars using destructive and non-destructive tests respectively. It is also presented the correlation between the IOT mortar static (E_{ci}) and dynamic (E) elasticity modulus. It is seen that 88% of the observed variation in the elasticity modulus is attributable to the approximate linear relationship between the dynamic and static values, a very impressive result. The results indicate that it is possible to obtain high-performance mortars to be used not only as rendering material but also as structural material in building construction.

1. Introduction

Humans use huge quantities of renewable and nonrenewable raw material resources and cause pollution as these resources are consumed. Rich countries consume the majority of resources, which indicates that this process will worsen as the level of consumption of resources will be uniform across different countries and will cause environmental imbalance [1]. Meadows et al. [2] predicts that during the 21st century, earth's ability to supply humankind's needs will end, resulting in the collapse of human civilization. According to Krausmann et al. [3], some limits have already been surpassed, and in the last century, the use of raw materials increased eight times. Therefore, humanity currently uses almost 60,000 million tons of raw materials annually. However, the most important environmental threat associated with their production was not exhaustion of nonrenewable raw materials but rather the environmental impacts caused by their extraction [4]. The estimated iron ore production in Brazil for 2015 was 751 million tons, which generated 260 million tons of iron-ore tailings (IOTs) [5].

A tailings dam is typically an earth-fill embankment dam used to store byproducts of mining operations after separating the ore from unwanted minerals which are an intrinsic part of the ore rock itself. The tailings facilities are site-specific systems that have environmental and physical characteristics. They represent a significant business risk that must be effectively managed. The disposal of IOTs represents an environmental risk in terms of conserving biodiversity, air pollution, and water reserve pollution in addition

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to accidents in tailings dams, which cause loss of life and environmental disasters [6].

According to the State Environmental Foundation, there are 744 tailing dams in the state of Minas Gerais, Brazil. Despite the large quantity of IOTs stored as trash, the usage rate is less than 10%. This low reutilization along with the increase in IOTs not only places tailing management in the mining sector in question but also poses serious environmental problems and risks to safety (tailing dams with a high risk of failure). With the recent strategies for sustainable development, the use of IOTs has received increasing attention throughout the world.

Currently, the greatest use of IOTs is in the recovery of degraded areas [7], in the re-extraction of iron ore and other metals [8,9], and as a raw material in producing construction materials, material for landfilling, and fertilizers [10]. The use of IOTs as a raw material for the production of construction materials is recent. Previous studies report various methods to use IOTs as additives in clinker and concrete as a substitute for sand in concrete [11,12], and siliceous materials in ceramics [13] and in autoclaved aerated concrete [14]. The use of IOTs in producing construction supply materials allows for sustainability in the mining industry and simultaneously increases clean production in the construction industry, reducing the demand for non-sustainable raw materials.

The substitution of cement or aggregate in concrete for recycled materials makes it a cleaner "green material" product. However, it is also necessary to ensure the durability of the material throughout its life cycle to attain true sustainability for concrete supplies [12].

IOTs have the potential to be used as a fine aggregate because they are relatively inert and the size of the tailing particles is significantly greater than that of cement. It has been verified that the use of IOTs can produce ultra-resistant concretes [15,1]. The use of IOTs in self-compacting concretes (SCC) was studied by [16]. A study using IOTs in masonry units is more recent [17,18]. The majority of the studies are focused on the characterization of IOTs and on determining the physical and mechanical properties of the construction products made with IOTs through experimental tests. Nondestructive tests (NDTs) have been underutilized to determine these properties.

The use of NDTs in determining the physical and mechanical properties of construction materials is fairly widespread, and recently, several new methods have been introduced, such as determining the dynamic modulus of elasticity using ultrasound, resonant frequency [19,20], decrement of free vibration [21], beam rotation [22], pulse rotation [23,24], and thermal methods [25].

Basically, the main goal of the paper is to characterize rendering mortars made of iron ore tailings to be used as an alternative building material. This characterization was mainly made by measuring its dynamic and static elasticity modulus.

2. Materials and methods

To make the test samples (TSs), high-initial-resistance Portland cement (CP V-ARI) and the IOTs (as fine aggregates) were used in two fractions: fine and granular IOTs (according to the granulometric curves in Fig. 1). Fig. 1 shows the variation of the cumulative percent passing (%P) with IOTs diameters (mm). The chemical composition, granulometric characteristics, and permeability of the IOTs are listed in Tables 1 and 2, respectively. The IOT samples were supplied by the company Samarco Mineração S.A. in Belo Horizonte, Minas Gerais, Brazil.

Six different mortar mix ratios were defined with the same consistency, 300 ± 15 mm, from the flow table, and the aggregate was varied to test its contribution to the plasticity. The usual amount used in mortars is 260 ± 10 mm. However, because in the mortars being studied, the fineness of the aggregates increased cohesion, to achieve adequate workability, it was necessary to adopt a higher value from the flow table. Table 3 presents the mortar mix ratio adopted for the study (cement: fine tailing: granular tailing: water).

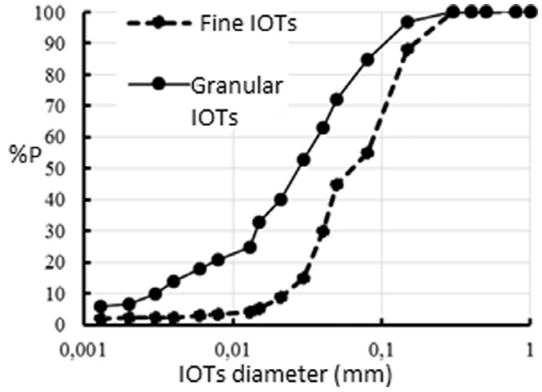

Fig. 1. Granulometric curve of the samples.

The cure test was based on the Brazilian Standard NBR 13279 (2005). The TSs made with these mortar mix ratio were subjected to damp cure and were tested after 28 days. The dimensions of the TS cylinders were 5 cm in diameter and 10 cm in length.

A visual preliminary analysis was also made using a stereoscopic magnifying glass in order to assess the mortar quality. The porous distribution and the cement paste/aggregate interface could be observed with details. A digital microscopic (Usb and zoom 1000x) with professional camera 2.0 MP were used herein.

2.1. Static modulus of elasticity

To determine the static modulus of elasticity (SEM), the Brazilian standard was used [26]. The load application was cyclic, with a speed of (0.25 ± 0.05) MPa/s. The test was conducted using an Emic/Instron universal test machine with electromechanical control, in which a load cell with a capacity of 100 kN was coupled.

The SEM was calculated according to the Eq. (1) below [26]:

$$E_{ci} = \frac{\sigma_b - \sigma_a}{\varepsilon_b - \varepsilon_a} \times 10^{-3}, \tag{1}$$

where E_{ci} is the static modulus of elasticity (GPa); σ_b is the greatest tension, 0.3 fc (MPa); σ_a is the basic tension, 0.5 MPa; ε_b is the specific average deformation of the test samples tested under the greatest tension; and ε_a is the specific average deformation of the test samples tested under basic tension.

2.2. Dynamic modulus of elasticity

To estimate the dynamic elasticity modulus (DEMi) of concrete $\underline{E}$, among other properties, the American standard [27] addresses the methods to measure the transversal, longitudinal, and torsional resonant frequency of prisms and concrete cylinders using forced resonance and impact methods.

Mechanical vibration analysis can be used to determine the modulus of elasticity of concrete structures. Propagating longitudinal waves in structures are considered non-dispersive, i.e., the propagation speed of this type of wave does not vary with the excitation frequency from the generating source [38]. Thus, the response from an impulse in the time domain divided by the effect of an instrumented hammer in the longitudinal direction of a test sample (TS) generates longitudinal, or "quasi-longitudinal", waves