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Contaminant removal from manufactured fine aggregates by dry rare-earth magnetic separation

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ABSTRACT

Manufactured fine aggregates have become a viable alternative to natural sands in construction and building all over the world, in particular where a sustainable source of the later is not available. Technologies that are now associated to processing these materials include vertical shaft impact crushing and dry classification, which have the direct ability to improve particle shape and control the amount of filler material, respectively. Granites and gneisses are among the rocks that are most commonly used for aggregate production worldwide. While composition generally creates no major issues in their application as coarse aggregates, the use of these rocks in production of manufactured sand can represent a challenge, mostly associated to the presence of appreciable amounts of contaminating minerals, in particular micas, which can have a negative impact on both rheology and strength of mortars and concrete. The present work demonstrates the improvement in the characteristics of three manufactured fine aggregates through dry rare-earth magnetic separation. It demonstrates that the mica/biotite content has been reduced significantly, leading also to a significant improvement in shape in the product. Magnetic separation has been found to have the added advantage of removing other deleterious minerals also present in these rocks, thus improving the brightness (given the dark coloration of mafic minerals removed) and potentially the performance of such fine aggregate in mortars, concrete and asphalt.

1. Introduction

Manufactured fine aggregates are being increasingly used as a more sustainable alternative to natural sands in different parts of the globe, as a response to the growing restrictions to the use of the natural material (Gonçalves et al., 2007; Anand and Reddy, 2014). Manufactured sands often differ from the natural product in respect to three main characteristics: particle shape, composition and amount of fines.

Some studies have demonstrated the effect of crushing process in the manufactured sand characteristics and performance, mainly showing the benefit of impact crushing over compressive (cone) crushing to improve particle shape (Gonçalves et al., 2007; Bengsston et al., 2009; Nanthagopalan and Santhanam, 2011; Lagerblad et al., 2014; Cepuritis et al., 2016). Besides shape, researchers have also addressed the implications of greater proportion of fines on the performance of manufactured fine aggregates, also investigating the use of dry classification to limit its proportion (Cepuritis et al., 2015).

Mineral composition of manufactured sand can also have an impact on its application on mortars, concrete and asphalt. The presence of sulfides, carbonates, reactive silica minerals (opal and calcedony), minerals resulting from weathering of feldspar minerals (kaolinite, “sericite”, “saussurite”, illite and chlorite), as well as foliated minerals has been associated to deleterious effects in mortars, concrete and asphalt (Anastasio et al., 2016).

Several rocks used for producing manufactured sands, in particular granite and gneiss, can have appreciable amounts of biotite. Biotite is a name used for a number of black mica minerals that have different chemical compositions but very similar physical properties. These minerals generally cannot be distinguished from one another without detailed laboratory analyzes and have the general composition $K(Mg,Fe)_{2\text{-}3}\,Al_{1\text{-}2}Si_{2\text{-}3}O_{10}\,(OH,F)_2$, and include minerals such as annite, phlogopite, siderophyllite, sastonite, fluorannite and fluorophlogopite (Klein and Dutrow, 2008). They are all characterized by perfect basal cleavage, breaking into platelets with smooth surfaces, low Moh’s hardness (2.5–3) and specific gravity that varies from 2.7 to 3.4 g/cm^3, several of which showing paramagnetism (Hunt et al., 1995).

The presence of biotite in manufactured fine aggregates is known to be detrimental to the performance of mortars and concrete (Danielsen

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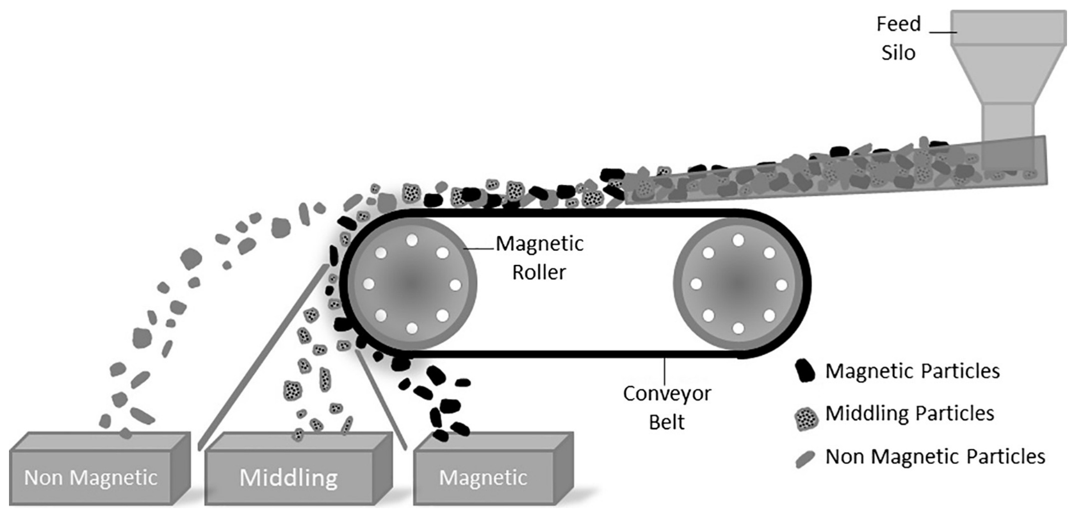

Fig. 1. Schematics of the dry rare-earth magnetic separator.

and Ruestatten, 1984; Wakizaka et al., 2001; Lagerblat et al., 2014), as well as asphalt (Miskovsky, 2004). Wakizaka et al. (2001) demonstrated that the presence of biotite in a manufactured sand resulted in reduction in the compressive strength of mortars, which was associated to the poor adherence of the cement paste to the surfaces of mica particles, whereas a negative effect of this mica on the mechanical properties of asphalt mixtures was associated to its ability of adsorb bitumen and create zones of weakness (Miskovsky, 2004). Further, biotite has also been associated to poorer workability of both mortars and concrete, resulting in greater water demand. The presence of other mafic minerals, besides biotite, can also have a more subjective, but important implication in their application in mortars: their darker coloration can limit some applications, particularly those associated to use of mortars for finishing surfaces in masonry. The challenge of using such rocks that contain appreciable amounts of biotite arises from the fact that the amount of this mineral often varies within a mineral deposit, making it difficult for the producer to ensure delivery of manufactured sand with a constant and controlled proportion of biotite.

Gneisses are the most abundant rocks in the State of Rio de Janeiro, Brazil (Silva et al., 2015). They are the basis of aggregate production in the state, also making up touristic landmarks such as the world known Sugarloaf and the Corcovado (Mansur et al., 2008; Silva et al., 2015). A recent study has shown that these rocks contain between 3 and 10% of biotite, on average, in quarries that produce crushed stone in the metropolitan area of Rio de Janeiro, with much higher contents in particular mine faces, which may even be classified as biotitite (Tavares et al., 2015).

Magnetic separation technology has evolved significantly in recent years, now making it possible to separate dry with increasingly higher magnetic field intensities with the aid of rare earth magnets (Wills and Napier-Munn, 2006). Such advances now allow applying magnetic separation using permanent magnets in separation of minerals that are only moderately paramagnetic from those that are diamagnetic.

The present work demonstrates the use of high-intensity dry magnetic separation to remove contaminants from manufactured fine aggregates from gneiss rocks from Brazil, with the aim of improving their response in mortars and concrete.

2. Experimental

Samples of fine manufactured aggregates, designated hereafter as A, B and C, were collected from three distinct quarries located in the metropolitan area of Rio de Janeiro, Brazil. Petrological analyzes identified them as gneiss: whereas types A and B are from the Rio Negro formation, C is from the Faccoidal formation (Silva et al., 2015). These samples were recognized, by visual inspection, to have different proportions of biotite. They corresponded to the fine product from industrial crushing circuits consisting of primary jaw crushing followed by three stages of cone crushing.

Samples were initially analyzed to determine their size distribution by sieving. Samples, with top size of 5.6 mm, were dry-sieved into five size classes (5.6–1.18 mm, 1.18–0.425 mm, 0.425–0.212 mm, 0.212–0.053 mm and finer than 0.053 mm) in a RO-TAP® sieve shaker. Samples contained in the four coarser size ranges were then washed using a fine opening screen (0.053 mm) to remove any possible material adhered and then dried in a lab oven at 100 °C for 24 h.

Preliminary liberation analyzes of particles contained in narrow size ranges were conducted by inspection using a stereoscopic microscope to estimate the proportion of particles that are either composed exclusively of the mafic minerals, felsic minerals and those that are locked. In this study a particle was considered liberated if more than 90% of its apparent area was composed of either mafic or felsic minerals.

Magnetic separation tests were conducted using a Rare-Earth Magnetic Separator, model RE-ROLL manufactured by INBRAS-ERIEZ, fitted with an 8 cm diameter roll containing Erium-3000® rare-earth magnets, with a 16 cm wide belt. Tests were conducted with the aim of removing the paramagnetic minerals, mainly biotite, from the manufactured sand samples. The samples were fed to the separator contained in the four coarser size classes previously separated. Particles contained in the finest size range (−0.053 mm) were not subjected to separation because they were assumed to be excessively fine for efficient dry separation. The laboratory scale device consisted essentially of a feed silo, a conveyor belt and a roller with rare-earth permanent magnets (Fig. 1), which produce a magnetic field with intensity of about 0.55 T, measured with the aid of a gaussmeter equipped with a probe.

The tests were conducted in two different stages (Fig. 2): (i) a rougher stage, fed with the originally classified sample, in which the rotor operated at 100 rpm; (ii) a scavenger stage, fed with the magnetic product from stage (i) and operated with a rotor speed of 130 rpm. Although the separator generates a middling product, it was incorporated in the magnetic product in all tests, so that only two products were generated in each test (Fig. 2). The frequency used in the vibratory feeder of the magnetic separator was low enough to ensure that there was approximately only a monolayer of material on the belt, guaranteeing that all particles are subjected to the highest magnetic field intensity.

Samples of the feed and products were then subjected to a number of analyses, in order to characterize their composition (chemical and mineralogical) and particle shape. This later was used in order to assess