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# Evaluation of fresh cement pastes containing quarry by-product powders

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## HIGHLIGHTS

- Use of quarry powders (gneiss and diabase) as a replacement for limestone filler showed satisfactory performance.
- Gneiss particles present lower flocculation than those of diabase and limestone.
- Filler mineralogy is not an influential factor in the yield stress (95% confidence level).

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## ABSTRACT

Large amounts of powders have been collected in quarries and the storage of these by-product dusts is a serious environmental concern. In this paper, the effects of limestone filler, diabase, and gneiss quarry powders on the properties of fresh cement pastes were investigated. The influence of the mineralogy and particle size distribution was evaluated by rheological methods on cement pastes containing the materials under investigation. In addition, in-situ particle size analysis of the fresh pastes was conducted to observe how these different by-product dusts affect agglomeration kinetics. Pastes containing quarry powders showed lower yield stress and lower viscosity than pastes containing only cement. The results show the benefit (in terms of paste rheology) of partial replacement of cement by diabase or gneiss powders, and the ability of these materials to be used as an alternative substitute to limestone filler as a mineral admixture.



## 1. Introduction

Mineral aggregate quarrying produces a significant amount of environmental waste in the form of fine material (quarry dust powder); this is especially a concern for the aggregate beneficiation process for manufactured fine aggregate for use in Portland cement concrete due to standards and performance requirements. Numerous standards, like the ASTM C 33 [1] and ABNT NBR NM 46 [2], limit the microfine (smaller than 75 μm) content, due to the deleterious effects on water demand and concrete strength [3].

In Brazil, quarries remove about 0.7–1 ton of fine material for every 50 tons of manufactured fine aggregate. In other countries, similar situations are reported by several researchers [4–6]. In most cases, quarries do not have adequate destination for this product. However, these powders can be used as a viscosity enhancer in cement mixtures, like self-compacting concrete (SCC).

SCC is a high performance concrete that must maintain adequate fresh state properties throughout the casting process. SCC requires adequate viscosity, as well as high deformability and high segregation resistance to be able to flow into restricted spaces and openings without segregation. To maintain adequate rheological properties, it is common to modify the paste phase by including viscosity-modifying agents (VMAs) to the mixtures and/or by adding large amounts of mineral admixtures. VMAs can be used to improve paste viscosity by increasing the water phase viscosity. However, there are a number of disadvantages to using a VMA, mainly the high costs and side effects in the mixture, such as set retarding and excessive air entrainment [3]. Limestone powder has been used in SCC to control the potential segregation and deformability [7,8]. However, where this material is not available, the use of alternative fine materials, such as quarry dusts, could be ideal for SCC applications.

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Fillers of basalt, granite, marble and limestone have been tested by several authors in pastes, mortars and concretes, mainly SCC. These authors reported improvements in the performance of these materials, including mechanical properties, workability and cost reduction [3,7,9–13]. Few or no studies have been conducted on other rock types concerning their performance as additives in cement mixtures.

The objective of this research was to evaluate the use of quarry dust of dibasic and gneissic origins as alternatives to limestone filler for use as a viscosity enhancer. Specifically, the rheological properties and the microstructure of fresh cement pastes were evaluated, and the influence of particle characteristics on these properties is discussed. The rheology of cement pastes and concrete is strongly related to the agglomeration of the cement particles [14], which in turn affects the microstructural development of mortar and concrete [15,16].

As the presence of different powder particles influences cement paste rheology and, consequently, its microstructure, understanding how these different quarry dusts impact rheological behavior is important to achieve a fundamental understanding of how to control the fresh state behavior of concrete containing these dusts. In this research, insight on the nature of agglomeration was obtained by measurements conducted using a focused beam reflectance measurement (FBRM) probe. The FBRM technique provides indirect observation of the dynamic microstructure of cement paste during mixing [17,18] through chord length measurements of the agglomerates.

## 2. Experimental study

### 2.1. Materials

A commercially available Portland cement classified as Type III by ASTM C150 [19] and Type CPV ARI by the Brazilian Standard ABNT NBR 5733 [20], was used in all of the mixtures. According to the cement manufacturer, it had a Blaine fineness of 394 $m^2$/kg, and specific gravity of 3.12. The oxide composition of the cement is shown in Table 1. A commercially available Type F polycarboxylate superplasticizer (SP) [21] was used in all of the mixtures. The solid concentration of the admixture was reported by the manufacturer as approximately 23%, with a specific gravity of 1.05. All the mixtures were prepared using deionized water.

Three different fillers were evaluated in this work. One filler was of limestone origin (represented as L), and two industrial waste fillers: a quarry dust powder of diabase origin (represented as D) and a quarry dust powder of gneiss origin (represented as G). The chemical and physical characteristics of the fillers are summarized in Table 2.

The fillers were obtained directly from quarries and the average particle diameter of the as-collected powders (denominated L0, D0, and G0 in Table 3) was between 33 and 38 μm. To evaluate the influence of particle size, each type of filler was ground until the average particle size was close to 15 μm, similar to that of the cement used. A ball mill was used to reduce the size of the particles. Depending on the hardness of the filler, more or less time was required to obtain the desired particle size (Table 3). The laser particle size distributions for cement and for all the as-received fillers and fillers after grinding are presented in Figs. 1–3, and were

**Table 2**
Chemical and physical characteristics of fillers.

| Filler | L | D | G |
|---|---|---|---|
| Origin | Limestone | Diabase | Gneiss |
| *Chemical analysis (%)* | | | |
| CaO | 54.03 | 8.48 | 1.12 |
| $Al_2O_3$ | 0.31 | 15.46 | 15.95 |
| $Fe_2O_3$ | 0.22 | 2.10 | 0.90 |
| $SiO_2$ | 0.85 | 51.88 | 70.13 |
| MgO | 1.91 | 4.58 | 0.69 |
| $K_2O$ | 0.02 | 0.76 | 6.22 |
| *Physical properties* | | | |
| Specific gravity | 2.80 | 2.82 | 2.77 |

**Table 3**
Impact of grinding on average particle size, $D_{50}$, of fillers.

| Filler | Denomination | $D_{50}$ (μm) | Grinding time (h) |
|---|---|---|---|
| Cement | C0 | 15.19 | 0 |
| Limestone 0 | L0 | 38.09 | 0 |
| Limestone 1 | L1 | 25.22 | 1.5 |
| Limestone 2 | L2 | 16.45 | 7.5 |
| Diabase 0 | D0 | 33.01 | 0 |
| Diabase 1 | D1 | 24.22 | 1.5 |
| Diabase 2 | D2 | 16.12 | 6.0 |
| Gneiss 0 | G0 | 34.15 | 0 |
| Gneiss 1 | G1 | 25.09 | 9.0 |
| Gneiss 2 | G2 | 16.56 | 18 |

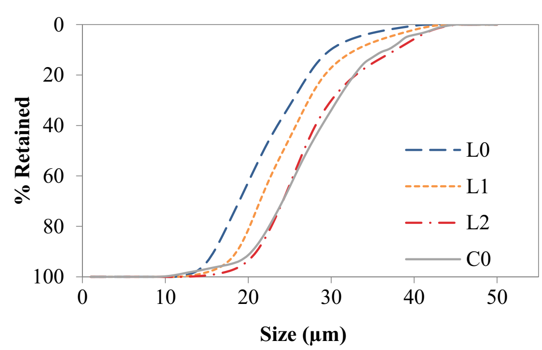


**Fig. 1.** Limestone – Laser particle size distribution.

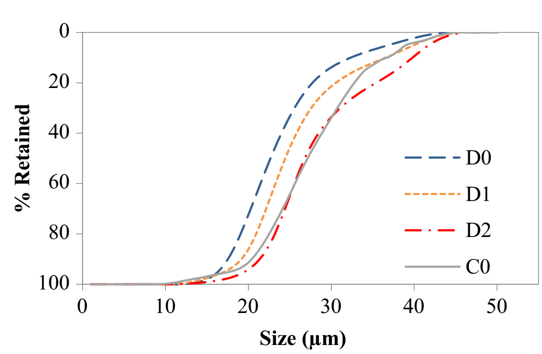


**Fig. 2.** Diabase – Laser particle size distribution.

**Table 1**
Oxide composition of the cement.

| Basic oxides | $SiO_2$ | $Al_2O_3$ | $Fe_2O_3$ | CaO | MgO | $SO_3$ | $Na_2O$ and $K_2O$ |
|---|---|---|---|---|---|---|---|
| Amount (%) | 19.04 | 4.33 | 2.73 | 61.5 | 4.42 | 2.69 | 0.69 |