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Experimental investigation of the relationship between mineral content and aggregate morphological characteristics using the improved FTI system and XRD method

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HIGHLIGHTS

- Measured aggregate morphological characteristics and mineral content by weight.
- Established correlations between mineral content and aggregate morphological characteristics.
- Compared predicted morphological parameters with FTI measurements.

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ABSTRACT

Mechanical performances of concrete materials are greatly influenced by morphological characteristics of aggregates. Aggregate morphological characteristics are closely related to mineral content, the size and shape of mineral grains, the spatial distribution of inner pores, and defects. This study investigates the relationship between aggregate morphological characteristics and mineral content by weight for thirteen aggregate samples that were produced from six types of rocks. The thirteen samples were imaged using the improved Fourier Transform Interferometry (FTI) system; mineral composition and weight content of minerals were determined using the X-ray diffraction (XRD) method for the six types of rocks. Pairwise correlation analysis and multiple linear regression analysis were performed to establish quantitative relationships between mineral content and morphological characteristics of aggregates. Research findings from this study can facilitate aggregate selection based on mineral content in order to produce aggregates with desired morphological characteristics.

1. Introduction

Concrete materials are widely used in critical structures, such as buildings and underground structures [59,37,25], bridges [41], tunnels [5,6,43], and highway pavements [55,16]. Even though the unit price of concrete materials is very low, annual consumption worldwide is huge. A small improvement on mechanical performances would eventually save billions in the service life of critical structures. Improving mechanical performances of concrete materials can be achieved by appropriate selection of composite materials. In concrete materials, aggregate is a major component, taking up to 90% by volume. Research shows that aggregate morphological characteristics greatly influence the interlocking effect of the aggregate skeleton [11,54,58] and the bonding effect of the aggregate-binder interface [33,44,15]. As a result, aggregate morphological characteristics influence mechanical performances of concrete materials, such as mechanical properties [46], fatigue and rutting performances [27,28], dynamic modulus [45], and friction resistance [34,31,32,53]. It is essential to select aggregates with desired morphological characteristics for better mechanical performances of concrete materials to improve field performances of critical structures.

Morphological characteristics describe spatial asperities of aggregate surface. Research shows that morphological characteristics of aggregates are closely related to mineral compositions and microstructures, including mineral content, inner porosity,

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inherent cracks, the size, shape, spatial distribution of mineral grains, etc. [13,10,26,49]. Among the aforementioned factors, mineral content greatly influences aggregate morphological characteristics [22,54,48], consequently impacting mechanical strength [19,51,35,9,49], polishing tendency [40,23,14,60], rheological properties [57], and ballast degradation [3] of aggregates. Better understanding of the fundamental relationship between mineral content and morphological characteristics can facilitate the selection of appropriate aggregates to achieve targeted engineering properties [61].

There are two categories of measurement methods to quantify morphological characteristics of coarse aggregates: indirect measurement and direct measurement. Indirect measurements [1,2] are not representative of actual morphological characteristics. Direct measurement using a caliper is tedious and time-consuming. Conversely, direct measurements using imaging analysis techniques utilize computational programs to rapidly analyze digital images of aggregates. Among various imaging analysis techniques, the improved Fourier Transform Interferometry FTI) system is capable to rapidly calculate three-dimensional coordinates of aggregate surfaces and accurately determine aggregate morphological characteristics in a cost-effective way [25,27].

On the other hand, X-ray diffraction (XRD) technique gives a unique pattern of diffraction peaks for the crystal structure of every major mineral constituent in samples. Qualitative and quantitative identification of minerals can be conducted by comparing the measured pattern of a sample to standard diffraction patterns. XRD has been frequently used to identify minerals in granular materials, such as soils [42], aggregates [4], and rocks [47].

Most studies of aggregates investigated the following correlations: 1) the correlation between mineral content and mechanical performances [51,35,9,49,62], 2) the correlation between morphological characteristics and physical properties [24,20,25], and 3) the correlation between mechanical properties and morphological characteristics [40,26]. However, very few studies had evaluated the relationship between mineral content and morphological characteristics for aggregates in a qualitative way [26]. Quantitative relationships are in urgent need to unveil the fundamental mechanism between mineral content and morphological characteristics of aggregates. Through the quantitative relationships, we will be able to better understand how mineral compositions influence morphological characteristics of aggregates. Ultimately, the quantitative relationships can facilitate the selection of aggregates with desired morphological characteristics according to mineralogical properties, eliminating tedious laboratory measurements of aggregate morphology.

This study uses the improved Fourier Transform Interferometry (FTI) system to measure morphological characteristics for thirteen coarse aggregate samples that were produced from six types of rocks. In this study, the mineral content of each type of rock was measured by XRD technique. The relationship between each morphological parameter and mineral content was determined through pairwise linear regression analysis. The objective of this study is to establish quantitative relationships between the morphological parameters and the mineral content for coarse aggregates.

2. Mineral content

Table 1 shows the rock type, size, origin, and mineral content of six types of rocks from Virginia State, including diabase from Bealeton, quartz diabase from both Leesburg and Goose Creek, quartzite from Stuarts Draft, granite from Garrisonville, and aplite from Piney River. Aggregates were produced from six types of rocks by either a cone crusher or an impact crusher.

Mineral compositions of rocks were determined using an Olympus BTX X-ray diffractometer (XRD), a portable and low power (10 W) unit that is capable of quickly analyzing a small amount of powder sample. Whole aggregate particles were crushed to pass a 150 μm sieve. A small amount of the powder sample was placed in a cell that vibrated in the unit causing the particles to move, presenting different orientations as they are exposed to the radiation beam. Reflections were recorded using a CCD detector. The unit was equipped with a Cobalt X-ray tube, and the analysis was conducted through a 2-theta range from 5° to 55°. Diffraction patterns were analyzed using XPowder Ver. 2010. 01.26, with the American Mineralogist Crystal Structure Database AMCSD) [8] to identify the minerals and estimate the weight content.

Fig. 1 plots the XRD analysis results of the six types of rocks. The mineral abbreviations are listed on each plot. The XRD analysis shows that Bealeton diabase consists of plagioclase, pyroxene, and quartz. Compared with Bealeton diabase, quartz diabase from Leesburg and Goose Creek includes an additional mineral of montmorillonite. The dominant mineral in quartzite from Stuarts Draft is quartz. Granite from Garrisonville primarily consists of hornblende, pargasite, quartz, and chlorite. The three lithologies of aplite from Piney River include the same mineral compositions of albite, quartz, epidote, and muscovite, which are at different contents by weight.

Table 1 presents the measurement results of weight content for each type of rock. Diabase from Bealeton consists of 54% of plagioclase, 24% of pyroxene, and 20% of quartz. Leesburg quartz diabase consists of 48% of plagioclase, 19% of pyroxene, 26% of quartz, and 5% of montmorillonte. Goose Creek quartz diabase consists of 45% of plagioclase, 22% of pyroxene, 24% of quartz, and 7% of montmorillonte. Garrison granite is composited of 32% hornblende, 11% of pargasite, 26% of plagioclase, and 6% of chlorite. The aplite from Piney River includes three sub-sets of rock. The first subset of aplite consists of 17% of quartz, 51% of albite, 17% of epidote, and 11% of muscovite; the second subset of aplite consists of 20% of quartz, 60% of albite, 3% of muscovite; the third sub-set of aplite consists of 51% of quartz, 26% of albite, 11% of epidote, and 10% of muscovite.

Table 1
Rock type, origin, crusher type, and mineral content of six types of rock.

Rock type	Origin	Crusher type	Plagioclase	Pyroxene	Quartz	Montmorillonte	Albite	Epidote	Muscovite	Hornblende	Pargasite	Chlorite
Diabase	Bealeton, VA	Cone	0.5517	0.2414	0.2069	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Quartz Diabase	Leesburg, VA	Cone	0.4884	0.1977	0.2674	0.0465	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Quartz Diabase	Goose Creek, VA	Impact	0.4588	0.2235	0.2471	0.0706	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Quartzite	Stuarts Draft, VA	Impact	0.0000	0.0000	1.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Granite	Garrisonville, VA	Cone	0.2692	0.0000	0.2179	0.0000	0.0000	0.0000	0.0000	0.3333	0.1154	0.0641
Aplite	Piney River, VA	Impact	0.0000	0.0000	0.1772	0.0000	0.5316	0.1772	0.1139	0.0000	0.0000	0.0000
			0.0000	0.0000	0.2022	0.0000	0.6067	0.1573	0.0337	0.0000	0.0000	0.0000
			0.0000	0.0000	0.5172	0.0000	0.2644	0.1149	0.1034	0.0000	0.0000	0.0000

Note: There were unresolved minerals in each type of aggregates in the XRD analysis, with the content less than 10% in total weight for every type of rock. In this study, the weight content of every mineral is determined disregarding unresolved minerals.