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Influence of mineral composition of siliceous rock on its volume change

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HIGHLIGHTS

- Shrinkage of siliceous rock aggregate shows correlations with its chlorite and bound water content.
- A simpler evaluation of shrinkage of aggregate using ignition loss from 105 to 600 °C is presented.
- The thermal expansion coefficient of siliceous rock can be evaluated by its quartz content.

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ABSTRACT

A method for predicting volume changes of aggregate during variations in humidity and temperature was studied. Siliceous rock aggregates commercially available in Japan were sampled from various regions and subjected to XRD (X-ray diffraction) analysis, thermal analysis, and volume change experiments. Drying shrinkage strain and the thermal expansion coefficient of the aggregates were found to be related to their mineral composition and bound water content. Experiments confirmed that drying shrinkage was correlated with the chlorite and bound water content of the aggregate, and that thermal expansion coefficients were correlated with the aggregate's quartz content.

1. Introduction

Studies on the shrinkage of aggregate in Japan began with the research of Goto and Fujiwara [1], which was prompted after an investigation by the Portland Cement Association (PCA) found that a bridge failure in South Africa was caused by the excessive shrinkage of concrete [2]. In 2003, a large-scale construction project was required to repair numerous cracks found in the Tarui viaduct in Wakayama Prefecture, Japan just one and a half years after its completion, leading to further active research into the properties of aggregate as a possible cause of the cracks due to concrete volume changes [3].

The quality of aggregate for concrete can be controlled by manipulating its bulk density, water absorption, wear resistance, and stability to sodium sulfate, as specified in the Japanese Industrial Standards (JIS A 5005). However, concrete containing aggregate that passes the standard tests can nevertheless undergo excessive drying shrinkage strain. Moreover, some specific types of sandstone are known to show large amounts of drying shrinkage, and the volume stability of aggregate is often given more importance than any other property in considering this phenomenon.

For a mixed design with both strength and fluidity as its major requirements, variations within the paste content that causes shrinkage and the aggregate content that restrains the shrinkage are small. Therefore, the drying shrinkage of aggregate greatly influences the drying shrinkage of concrete [4,5] as well as strength and Young's modulus of concrete [6].

At the same time, concrete members undergo various temperature changes. Due to the heat of hydration, elevated temperatures

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decrease the rate of concrete strength development at mature stages, as well as overall concrete strength. This is considered when determining mixture proportions according to the Japanese Architectural Standard Specification [7]. Difference in thermal volume change between aggregate and cement paste matrix causes damage in concrete and decreases splitting tensile strength [8]. Even after it hardens, concrete accumulates damage when exposed to elevated temperatures, and consequently, its physical properties deteriorate [6,9].

Currently, in terms of quality management for concrete in Japan, concrete drying shrinkage can be measured [7], but there is no way to test volume stability of aggregate on its own, except for sodium sulfate immersion tests [10] or an alkali aggregate reaction tests [11].

Some researchers assume that aggregates are a porous material, and that the capillary force of pore water is the driving force behind the drying shrinkage of aggregate. For example, previous studies have tried to clarify the relationship between drying shrinkage strain and specific surface area [1,12] or pore size [4] in aggregate. However, results from these experiments contain many anomalies and cannot explain the shrinkage of aggregate in terms of such physical properties. The swelling properties of clay minerals in aggregate may also be considered the driving force behind these anomalies, and the fact that some aggregate contains a high amount of such expandable minerals may also be a contributing factor.

Thus, it seems reasonable to propose a versatile prediction method with experimental approaches for drying shrinkage property and thermal expansion property based on mineralogy, because pure mineral crystal should have specific volume change properties based on its crystal structure.

Only one previous study examined drying shrinkage of concrete based on a mineralogical approach: Sakota reported the relationship between drying shrinkage of concrete (not aggregate) and its montmorillonite content [13]. To address this deficiency in the literature, the relationships between volume stability of aggregate and its mineralogical aspects are the main concerns of this paper.

Taking into account the current manufacturing processes of crushed aggregate and ready-mixed concrete, the selection of aggregate may pose some derivative problems. Hence, a simple estimation of aggregate quality to avoid excessive shrinkage and a concrete component designed to mitigate the shrinkage of concrete have been adopted as minimum countermeasures when fulfilling orders for concrete. A simple test using a wire strain gauge has previously been used to determine the drying shrinkage of aggregate [14,15]. The wire strain gauge method is fast, but needs improvement as a quality control measure because of some difficulties it faces in adhering to rock, limitations in specimen size, and possible uneven drying due to the watertight gauge cover and the anisotropy nature of the aggregate rock.

On the other hand, in recent years determination of mineral composition using XRD (X-ray diffraction)-Rietveld analysis has started to become established as a method in rock and soil engineering fields [16–18]. When minerals that shrink during drying can be determined with the XRD-Rietveld method, it may become a simple and useful method for the quality evaluation of aggregate because some expansive clay minerals that shrink in relation to the dehydration of interlayer water could have detrimental effects on the shrinkage of aggregate [13,19,20].

In this context, commercially available sandstone aggregates all over Japan were collected and subjected to humidity-controlled thermo-mechanical analysis to determine amounts of drying shrinkage and the thermal expansion coefficient in three directions. XRD-Rietveld analysis was performed to study correlations between amounts of expansive clay minerals, amounts of drying shrinkage, and thermal expansion coefficients.

Furthermore, with reference to the simple identification method for clay minerals used in the field of applied geology [21], a simple evaluation method for the shrinkage behavior of aggregate is discussed based on the ignition loss and the related bound water contents. This is an indicator of the association of number of hydroxyl groups in clay minerals with the amount of drying shrinkage of aggregates.

2. Materials and methods

2.1. Aggregate

Twelve types of crushed siliceous rock aggregates denoted A to L were collected from various parts of Japan. All samples were collected from commercial crushed coarse aggregates, and were assumed to be a single rock type based on external observation. The origins of the aggregates are shown in Fig. 1, and the results of their chemical analysis with wavelength-dispersive X-ray fluorescence spectrometer (XRF) are shown in Table 1. Each aggregate was crushed into a powder with particle size under 150 μm, and the pressed powder pellets were used for XRF measurement.

Samples J and K ware taken from the same locality. Some aggregates commercially available as sandstone were not sandstone in reality, as indicated by the polarization microscopy observation shown in Table 2. These included a tuff subjected to thermal metamorphism (A), a shale stone (B), a siltstone (H) and a mudstone (L), and all were sedimentary rocks with siliceous components. All the aggregates were sufficiently dense and met the requirements of density and water absorption specified by the Japanese Industrial Standards.

All aggregates were cut into cubic specimens of side length of approximately 8 mm, and their length change isotherms and thermal expansion coefficients were measured, as described in Section 2.4. After the volume change measurement, the cubic samples were crushed into a powder with particle size of approximately a 150 μm, and used for X-ray diffraction analysis and thermal analysis, as described in Sections 2.2 and 2.3. A

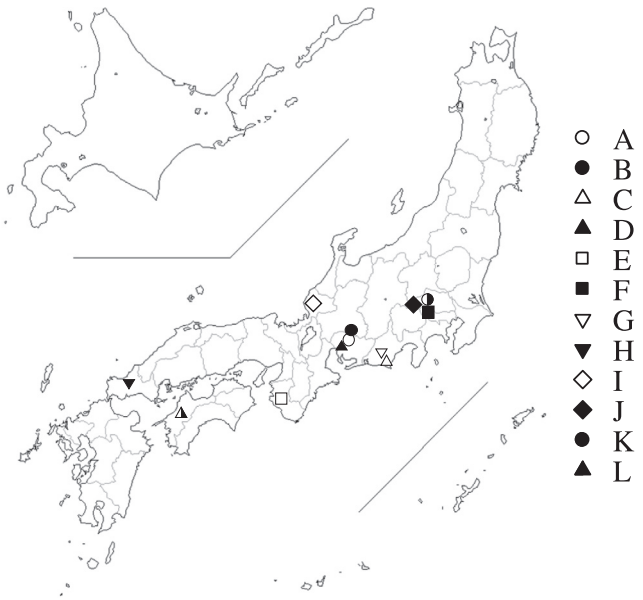

Fig. 1. Map of aggregates' localities.