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Experimental study of filling capacity of self-compacting concrete and its influence on the properties of rock-filled concrete

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ABSTRACT

Rock-filled concrete (RFC) was developed in China mainly for large-scale concrete construction. The distinctive casting procedure of RFC makes it highly dependent on the filling capacity of self-compacting concrete (SCC). This study investigated two of the most controversial issues regarding RFC—the filling performance of SCC and the large interface between SCC and rocks. These issues were examined through an experimental setup designed to stimulate SCC flow in rock skeleton. The effects of different factors (aggregate size, yield stress, etc.) on the filling capacity of SCC and the properties of RFC were investigated on the basis of filling rate, cross-section porosity, and interface microstructure. Two clogging mechanisms were summarized from literature and used to explain the experimental results. The findings indicate that the interface microstructure of RFC greatly depends on the filling performance of SCC which is significantly affected by the size and condition of the large rocks.

1. Introduction

Rock-filled concrete (RFC) is a type of concrete developed by Tsinghua University in 2003. It has been used in more than 40 projects in China, most of which are large-scale concrete construction projects in hydraulic engineering. On the basis of the technology of self-compacting concrete (SCC), the construction process of RFC involves two major steps: (1) filling in-situ formwork with large-scale rocks (grain size >30 cm) that pile on one another under gravity, and (2) pouring fresh SCC into the pre-packed rock skeleton to fill the voids between rocks and produce a consolidated concrete structure [1]. The application of large-scale aggregates presents many advantages, such as less cement usage, less deformation, less hydration heat, no vibration, faster construction speed, and less CO_2 emission. Nonetheless, these advantages come with concerns, among which the most controversial are (1) whether SCC can effectively fill the spaces between aggregates and (2) whether the large interfaces between SCC and rocks will become a weak part and threaten the strength and durability of RFC.

The capacity of SCC to pass through obstacles and to fill the formwork has recently become a research focus [2–5]. Although fresh SCC is known for its high flowability and has been successfully used to fill formwork of different shapes and configurations, potential issues remain when it is used under certain circumstances, such as flow through dense reinforcements. In these cases, the coarse aggregates in SCC may form stable granular arches at restricted zones between obstacles which thereby resist the flow, as long as the size of the coarsest particles is not far from the characteristic size of obstacles [2]. This issue is of paramount importance to RFC because the properties of RFC highly depend on the filling process of SCC. Combining existing studies on granular blocking and their own experimental results, Roussel et al. [2] claimed that granular blocking is a matter of probability, and that this probability may be influenced by many factors such as the volume fraction of coarse particles, the grading and shape of aggregates in SCC, etc. Most of these factors are related to SCC, while ratio between the diameter of the coarse particles and the free spacing between obstacles is the only factor related to the obstacles. This ratio is very important to the study of casting process of RFC, in which whether SCC can effectively fill the voids between large rocks may be closely related to the physical properties of the rocks. Previous studies on granular flow through an outlet [6–9] show that there may be a critical value of the size ratio between outlet size and particle diameter (jamming threshold). If the value of the size ratio is above this threshold, flow will not be blocked.

However, existing studies in passing and filling ability of SCC are insufficient for determining the best strategy for addressing SCC flow in rock skeleton. In RFC, the rock skeleton is a product of the random packing of particles with different sizes and shapes, which is more like a porous media (PM). The flow paths in rock skeleton consist of various void spaces between aggregates that are far more complex and heterogeneous than those in any regular reinforcements or filtration sheets. Pore-scale network is a PM model that represents the topological features of PM and can be used to study fluid with yield stress at microscopic scale [10–12]. In this model, void space is described as a network of pores connected by throats. The pores and throats are assigned an idealized geometry, and rules are developed to determine

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fluid configuration and transport in these elements [11]. However, the analytical expressions of throats are based on the concept of equivalent radius and are therefore not representative of reality because actual void space retains highly complex shape and connectivity [12]. Therefore, to investigate the casting process of RFC, in this study a laboratory experimental setup was designed and fabricated to simulate SCC flow in rock skeleton by using self-compacting mortar (SCM) and large aggregates. Several factors related to the properties of SCM and aggregates were selected as variables, and their effects were carefully investigated.

In some previous researches, the interfacial transition zone (ITZ) has been regarded as a weak link in concrete that may significantly undermine the mechanical properties and permeability of concrete [13,14]. As for conventional concrete, wall effect and microbleeding around aggregate surfaces are believed to be possible causes of the ITZ formation [13,15]. When it comes to RFC, properties of these large interfaces may highly depend on the filling capacity of SCC. Accordingly, in this study the microstructure of the interface in RFC-type concrete was also investigated by means of backscatter electron (BSE) image analysis.

This paper aims to provide a preliminary understanding of the filling capacity of SCC in rock skeleton, as well as the consequential properties of large interfaces between SCC and rocks with regard to the effects of carefully selected parameters.

2. Materials and methods

2.1. Materials

ASTM Type I Portland cement provided by Lafarge North America and Class F fly ash (as a replacement for 30% cement as supplementary cementing material) were used in all tests. Sand and coarse aggregates were provided by Ozinga and Thelen Sand & Gravel, respectively. In the laboratory, coarse aggregates were washed and sieved to three different size ranges: small (12.7 mm to 19.1 mm), medium (19.1 mm to 25.4 mm), and large (25.4 mm to 38.1 mm).

2.2. Experimental setup

To study the flow process of SCC flow in rock skeleton, an experimental setup was designed and fabricated using transparent acrylic plastics (Fig. 1) while SCM and large aggregates were used to simulate SCC and rocks respectively. The test box is divided into two chambers by a release door. SCM first flows into chamber 1 and then flows through the aggregate skeleton packed in chamber 2 after the release door is lifted. Considering that the reservoir has a relatively large bottom area, the change of the height of SCM in the reservoir is disregarded, and the height of the reservoir is fixed at 50 cm to ensure that each test has the same initial pressure. The reservoir has artificial slopes to facilitate SCM flow into the connecting tube. Chamber 2 was not sealed at the end of the removable lid in order to let the air out during the test. The pressure at each cross-section in chamber 2 was considered uniform because the pressure gradient was sufficiently small since the height of chamber 2 was much smaller than the height of the reservoir.

2.3. Experimental procedure

1. A mold release agent was placed on the inner surface of the test box. The removable lid, release door and plastic lattice (to prevent aggregates from falling into chamber 1 after the release door is lifted) were placed. The aggregates were weighed and vertically stacked in chamber 2.
2. The test box was laid on the ground, and the removable lid was secured through the placement of heavy bricks of concrete and metal on it.
3. The connecting tube, supporting frame, and fluid reservoir were installed. The inner surface of the tube and the reservoir was dampened before installation.
4. When SCM is ready to use after mixing, slump flow test was conducted first and in the meantime the remaining mortar was continuously poured into the reservoir. The mortar in the reservoir was stirred for 30 s with a stick to remove trapped air bubbles.
5. The release door was lifted properly to enable SCM to flow into chamber 2 under pressure. Nguyen et al. [16] emphasized that in the L-box test, the release door should be lifted slowly to eliminate the influence of other parameters. The slow lifting causes the final shape to depend only on the yield stress of fluid. The lifting duration was set at 4 s.
6. After SCM at the wall appeared to stop, a wait interval of 5 min was applied before the release door was closed.
7. The connecting tube, reservoir, and supporting frame were removed. The SCM was left to stand in the test box to set under a laboratory environment (23 °C, 60% humidity).
8. After 24 h, the test box was disassembled and the concrete specimen was weighed in chamber 2. Then, the text box was placed in the curing room (20 °C, 90% humidity).
9. After 13 d, the specimen was cut into several sections, with each cross-section photographed. The specimens were subsequently stored in the curing room for another 2 weeks.
10. After 28 d, the cross-sections were sliced into small pieces for sample preparation for microstructure tests.

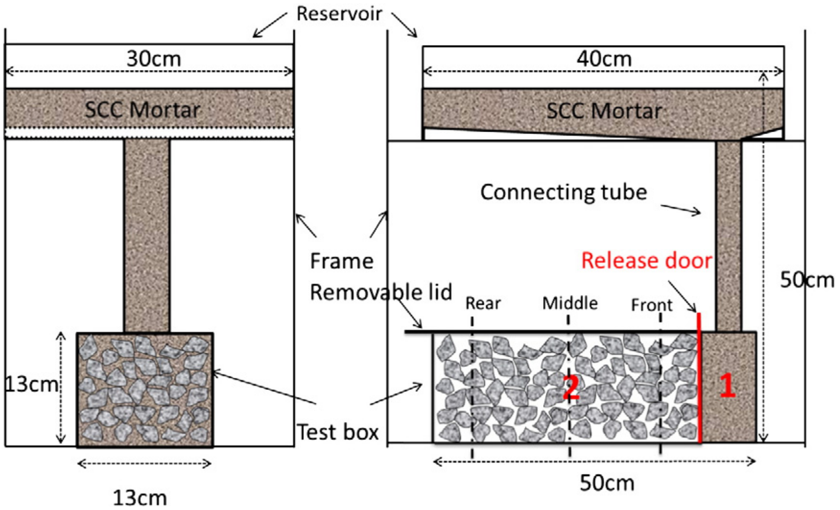

Fig. 1. Design profile of the experimental setup.