Construction and Building Materials 84 (2015) 30–38

Contents lists available at ScienceDirect

Construction and Building Materials

journal homepage: www.elsevier.com/locate/conbuildmat

Experimental investigation of flow of fresh self-compacting concrete in improved L-box

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HIGHLIGHTS

- Flow observations by both improved L-box and image processing technique are operated.
- The stable flow surge profile is assumed to be divided into six flow zones.
- A stable laminar flow zone is highlighted for further rheological solving.
- An empirical fitting model of stable flow depth profile with distance is developed.
- The improved L-box test is also available to test workability parameters.

ARTICLE INFO

Article history:
Received 10 September 2014
Received in revised form 3 March 2015
Accepted 8 March 2015
Available online 19 March 2015

Keywords:
Fresh self-compacting concrete
Dam break
Open channel flow
L-box test
Experimental results

ABSTRACT

To approach the rheological testing method based on L-box test for obtaining internal rheological parameters of fresh self-compacting concrete (SCC), an improved L-box without fiber bars and end wall is developed, and a flow investigation utilizing an image processing technique is operated. Specifically, the improved L-box test method is able to accurately reconstruct the process of free-surface evolution of fresh SCC when it is suddenly released in an open channel. The process involves the dam-break problem and open channel flow problem. In addition, by applying the image processing technique, the flow of fresh SCC in improved L-box (i.e. the front position of time-dependent and surge profile evolution), is easily observed and analyzed. By analyzing the experimental results, we conclude the time-dependent flow front position is governed by two regimes: an inertial regime and a pseudo-equilibrium regime. The flow surge plane is assumed to be divided into six flow zones (at the surge profile during the stable flow in pseudo-equilibrium regime). Simultaneously, a stable laminar flow zone is highlighted for further rheological solving. Additionally, by considering the fact of the most of the depth profiles in stable flow are convex curves in the experiment, a crude empirical fitting model is developed, and then the process of physical interpretation and verification is given. The comparison of results among improved L-box test and other tests shows that the improved L-box test is also available to test the workability parameters (i.e. penetrability, fillibility, et al.). Hence, this work is of significance for the further theoretical analysis and numerical simulation on the flow behaviors of the fresh SCC. The work may also interest the researchers who try to develop a convenient testing method in order to determine the rheological parameters of fresh SCC.

1. Introduction

Generally, the properties of fresh self-compacting concrete (SCC) [1–5] are characterized by either workability parameters or rheological parameters. The workability parameters are tested from the workability tests (i.e. slump test, L-box test, V-funnel test, et al.), while the rheological parameters are obtained from the rheological apparatus tests [6–10] or some rheological testing methods based on workability tests (i.e. slump test, L-box test [11], et al.).

However, presently almost researchers and technicians focus on the rheological parameters testing methods, rather than the workability testing methods [1–11]. The main reasons for this are due to the rheological parameters are the internal material

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http://dx.doi.org/10.1016/j.conbuildmat.2015.03.056
0950-0618/

parameters characterizing the nature of flow property of fresh SCC, since the workability test system [5] is developed for describing the entire engineering properties (i.e. workability). The workability parameters obtained from the system are considered as external engineering parameters, which are unable to straightly represent the nature of flow property.

Furthermore, at present, a well accepted rheological apparatus test has not been developed yet [1–11], and some workability test-based rheological testing methods give us some clues for some improvement of L-box test [11]. Therefore, it is available for us to propose a new convenient method in order to obtain the rheological parameters by L-box test. In detail, through the literature review, some improvement of L-box test has obtained initially in workability testing. For example, the LCPC Box test was developed by Roussel [12], and a method for testing the segregation of fresh SCC on the base of L-box test was improved by Bui et al. [13]. Additionally, other improvements of L-box test have developed focused on rheological parameter testing are also presented. For example, a method for determining the yield stress τ_0 was proposed by Nguyen et al. [11], which is a great development of L-box test-based rheological parameter testing.

However, it leaves us a challenge to obtain the rheological parameter viscosity by L-box test. Because in the presented L-box tests, the flow behaviors is too complex to be characterized, and very few experimental investigations on the flow behaviors are available in the literature yet.

Specifically, in presented L-box test, the flow problem is complex to solve the relation between the rheological parameter viscosity and the flow behaviors. This flow procedure approximately contains four aspects: the penetration problem caused by the fiber bars, the dam break problem, the open channel flow problem, and the interferential flow problem caused by the end wall of the open channel. Nevertheless, the solving of relation between viscosity and flow behavior needs a convenient testing of flow process with a time-dependent parameter. And both the dam break and open channel flow are fully necessary for this need.

It is because that, dam break is a type of suddenly release flow of fluid on a plane (e.g. slump flow) or in an open channel (e.g. L-box test), or in other boundary conditions. And dam break leads the existence of an initial kinetic energy for the subsequent flow of fresh SCC in L-box test. Additionally, open channel flow is a type of liquid flow within a conduit with a free surface. Considering on a fixed test conditions (i.e. a rectangle cross-sectional channel with both fixed width and boundary roughness, and a fixed mass with an initial kinetic energy, et al.), the behavior of open channel flow of fresh SCC is governed by the effect of viscosity relative to inertia, represented by the Reynolds number. Hence, the open channel flow during L-box test is able to be applied to characterize viscosity, and describe both passing ability and filling ability.

Additionally, due to lacking of relative literature, the experimental investigation of flow in L-box test is necessary for testing the rheological parameters. In detail, the experimental investigation is the foundation work for the rheological solving, since the investigation may obtain initial description of flow behavior, and it is helpful for further rheologically analysis. However, very few literature involved the investigation can be obtained [11,14–16]. Furthermore, by study the method on the investigations of the spreading of viscoplastic fluid which were operated by Cochard and Ancey [17–19], the image processing technique mentioned in their work may be an inspirational and available method for investigation in our work.

Hence, this work aims at both the simplifying of L-box by taking off the fiber bars and the end wall of the open channel, and the investigation of the flow of fresh SCC in improved L-box by applying an image processing technique.

In Section 2.1, we outline the techniques developed for this purpose, and we also present the experimental procedure. In Sections 2.2, 2.3 and 2.4, we describe how the fluid samples were prepared and characterized. Section 3 is devoted to express the experimental results. In Section 4, we discuss the experimental results and present some comparison of results among improved L-box test and other tests. A number of conclusions are drawn in the last section.

2. Experiments and materials

2.1. Experiments

2.1.1. Improved L-box

In order to simplify the flow procedure of fresh SCC in ordinary L-box test, we obtain an improvement of L-box by taking off the fiber bars and the end wall of the open channel (see Fig. 1). Subsequently, the flow relates to dam-break problem and open channel flow problem (see Fig. 2).

2.1.2. Experimental set-up

The dam-break and open channel flow experiment consist of the sudden release of a finite volume of fresh SCC into a horizontal open channel [20–22]. Initially, the fluid is placed in the reservoir of the improved L-box, as sketched in Fig. 2. It is then unleashed by lifting the dam gate, and it flows driven by gravitational forces. The initial conditions (volume of fluid, rheological features, density) and the boundary conditions (surface roughness, dimensions) can easily be altered and controlled, which makes this test very appropriate to understand time-dependent flows. In that case, experimentalists were satisfied with the measurement of the front position over time since this position can be accurately monitored experimentally (Fig. 3). The situation is markedly different for study on the flow of fresh SCC, for which one is interested in both the front position and free-surface shape, which is a delicate experimental task. To take up this challenge, we apply an imaging system (Fig. 3), which makes it possible to accurately reconstruct the free surface of an avalanching mass of fresh SCC.

The procedure of the experiment is as follows:

(a) Setting sample in reservoir – the improved L-box is set levelly, and the fresh SCC sample is loaded in the reservoir (Fig. 2a).
(b) Starting image processing – the camera is turned on to take 24 images per minute (Fig. 3).
(c) Dam break modeling – the gate of the reservoir is pulled up, which causes a dam break (Figs. 2b, and 3).
(d) Open channel flow modeling – the sample is flowing in the open channel after the opening of dam gate (see Figs. 2b, and 3).
(e) Producing of flow profile from images – when the sample stops flowing, we turn off the camera and save the images. From the images of the flow in improved L-box, we obtain the typical images in following conditions: when the front position of the sample reaches the distance of 150 mm, 250 mm, 350 mm, 450 mm, 550 mm, 650 mm and 700 mm of the open channel; or the sample is in the stable flow; or in the stopping of stable flow; or the sample ends flowing. And then, all the flow profiles are obtained from these typical images.

2.2. Materials

In the experiments, the cement (C) is Hefeng cement (32.5R), in Hengyang city, China. The fly ash (FA) is a first degree fly ash with high activity, and its density is ρ FA = 2400 kg/m^3. The sand (*S*) is middle size sand with the density ρS = 2650 kg/m^3 .The particle size of grove (*G*) is between 5 and 20 mm, and grove's density is ρG = 2700 kg/m^3. The super-plasticizer (SP) is poly-carboxylate super-plasticizer

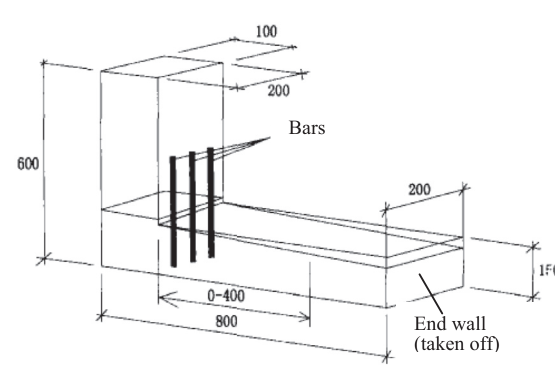

Fig. 1. Dimensions of L-box in the experiments (unit: mm).