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Estimation of rheological properties of UHPC using mini slump test

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HIGHLIGHTS

- A new method of estimating the rheological properties UHPC using mini slump test was proposed.
- The correlation between the spreading diameter-time relationship and the rheological properties were assessed.
- The rheological properties of UHPC could be estimated quantitatively through the mini slump test.

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ABSTRACT

This paper reports a method for estimating the rheological properties of ultra-high performance concrete (UHPC) by applying a mini slump test that can be used easily on-site. Computational fluid dynamic (CFD) analysis of the mini slump test within the scope of viscosity and yield stress of UHPC was performed and a simple equation that expresses the correlation between the variation of the spreading diameter over time obtained from the analysis and the rheological properties was proposed. The mini slump test was carried out on four types of UHPC mixtures and the rheological properties were estimated from the proposed equation, and verified by a comparison with the viscosity and yield stress measured directly using a rheometer. The comparison showed that the rheological properties of UHPC could be estimated quantitatively using mini slump test.

1. Introduction

Ultra-high performance concrete (UHPC) is a new type of material with outstanding mechanical properties as well as high durability and self-compatibility. Studies of the mixtures design [1], establishment of materials model [2] and the behavior of the structural members of UHPC [3] have been conducted. Currently, research on the application of the UHPC to actual structures are ongoing [4]. UHPC shows considerably higher viscosity than normal concrete [5], and it is necessary to maximally reduce the viscosity within the range of maintaining the mechanical performance to secure the appropriate workability that can be applied easily on-site. In addition, the management and control of the workability and fluidity on early stage UHPC (fresh UHPC) must be achieved strictly on-site. For this purpose, a simple method of quantitatively estimating the rheological properties of the fresh UHPC in the laboratory and on-site is necessary.

Recently, a method of estimating the construction performance, including pumping, pouring, compacting, and lateral formwork pressure, more accurately by measuring the viscosity and yield stress quantitatively using experimental equipment, such as viscometers or rheometers, has been proposed [6–10]. On the other hand, these rheology test devices are too expensive for general use in construction sites, so they are used mostly in laboratory scale tests. Several studies have developed a method for quantitatively estimating the rheological properties of cementitious materials through a mini slump test that can be conducted easily on-site. Roussel et al. (2005) proposed a method for estimating the yield stress of the cement paste through a theoretical approach that considered the final diameter, surface tension of the fluid, and the contact angle between the fluid and the surface of the floor, which are the results of a mini slump test [11]. Tregger et al. (2008) confirmed that the theoretically proposed estimation method produced different results from those of the actual measurements of the rheological properties of the material. In addition, the viscosity and yield stress were measured on cement pastes with various mixtures using a rheometer, and a mini slump test was performed simultaneously. The results of this experiment revealed the correlations between the final diameter and the yield stress and

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between the final spread time and the viscosity/yield stress [12]. However, these correlations have limitations because they include a high level of error, which can lead to different rheology results. Farrara et al. (2012) tried to obtain correlation between fundamental rheological properties and field test measurements, especially mini-cone slump flow test. However, to determine plastic viscosity, cone test designated in EN445 is additionally needed and moreover the results still showed discrepancy [13].

Therefore, this paper proposes a more accurate method for estimating the rheological properties by considering the changes in diameter according to the time measured at the mini slump test. For this purpose, computational fluid dynamics (CFD) analysis, which simulates the mini slump test within the range of rheological properties of the UHPC, was performed. The correlation between the spreading diameter–time relationship, which is the result of CFD analysis, and the rheological properties was analyzed, and the method of estimating the rheological properties of the materials through a mini slump test was proposed. To verify the proposed method, a mini slump test was performed on 4 UHPC mixtures, and the rheological properties estimated by the proposed method and the rheological properties measured directly with a rheometer were compared.

2. CFD analysis for mini slump tests

2.1. Analysis method

As shown in Fig. 1, CFD analysis, which simulates the mini slump test within the range of the rheological properties of the UHPC, was performed to evaluate the correlation between the spreading diameter as a function of time and the rheological properties. A commercially available analysis program was used to analyze the results of CFD [14].

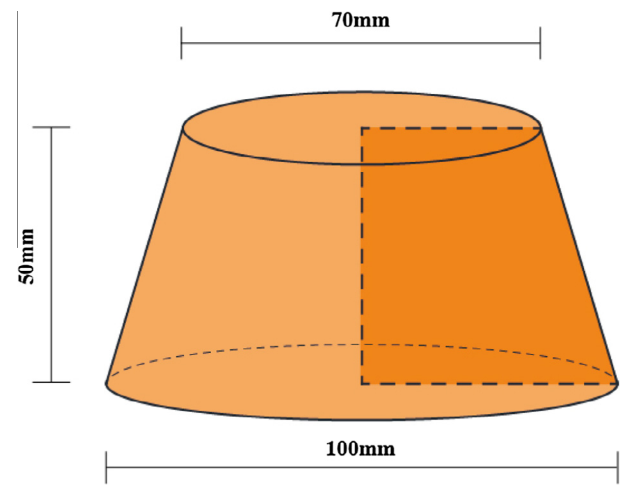

Fig. 2. Dimension of mini slump cone.

Fig. 2 illustrates the dimensions of the mini slump cone. Modeling was performed using cylindrical coordinates for the axis-symmetry, as shown in Fig. 3. Fig. 3 presents the modeling with the inner aspect of the mini slump cone, indicated by the bold line, filled with UHPC and air in the external aspect of the cone. The unit weight of the UHPC was assumed to be 2500 kg/m^3, and gravity was applied to all sections of the analysis domain. The no-slip boundary condition was applied to the interface between the material and the floor.

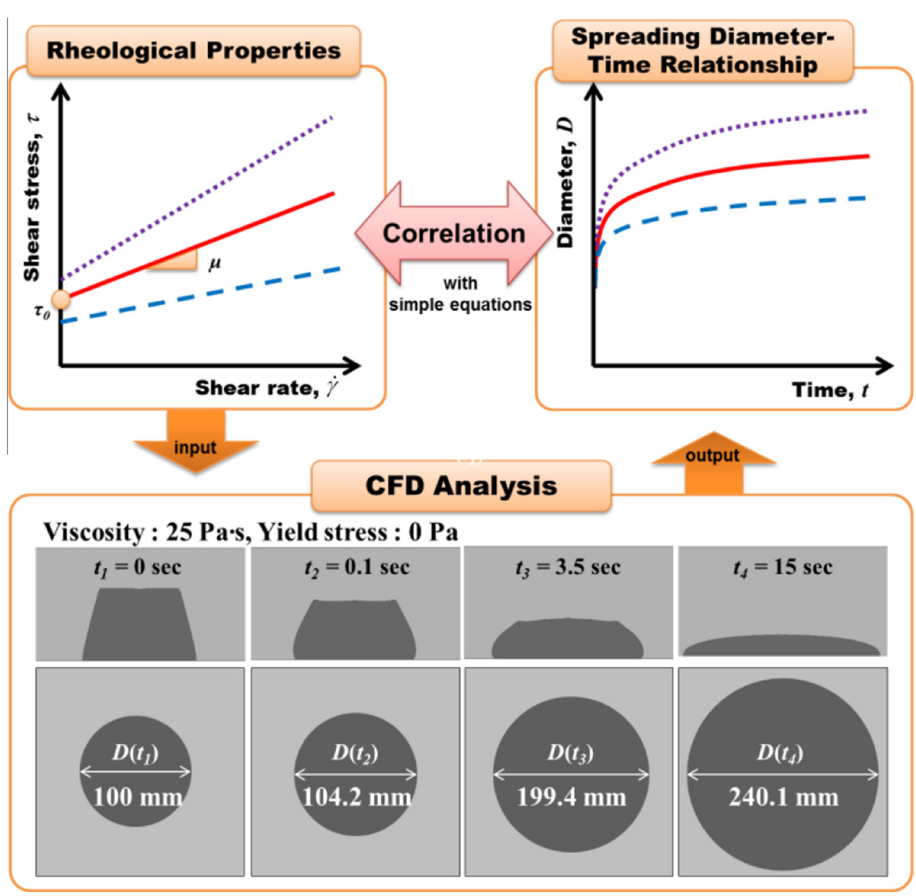

Fig. 1. Correlation of spreading diameter versus time curve with rheological property through CFD analysis.