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Concrete pumping prediction considering different measurement of the rheological properties

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HIGHLIGHTS

- The effects of different rheological measurements on predicting the concrete pumping were examined.
- The plastic viscosity of the lubrication layer plays a governing role in determining the pumping performance.
- The values of lubrication layer thickness should be altered depending on the rheological properties of lubrication layer.

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ABSTRACT

This study examined the effects of different rheological measurements on predicting the concrete pumping. For two representative pumping layers in a pipe, two different measuring systems using ICAR and Contec5 for bulk concrete layer, and tribometer and Brookfield viscometer for the lubrication layer were used to determine the rheological properties. From rheological analysis, the plastic viscosity of the lubrication layer plays a governing role in determining the pumping performance. The measured results from the Brookfield viscometer showed a 30% higher value than those of the tribometer. From the relationship between the plastic viscosity and thickness of the lubrication layer, it was found that the values of lubrication layer thickness should be altered depending on the rheological properties of lubrication layer. After applying 2.6 mm thickness for Brookfield viscometer system contrasting with 2 mm for tribometer, the prediction accuracy has changed from 68% to 84%. Therefore, to increase pumping prediction accuracy, it is necessary to mutually consider the lubrication layer thickness and corresponding rheological properties under the selected measurement systems.

1. Introduction

Concrete pumping has become common technique for placing concrete in the construction of various structures and its use is increasing because of the increased demand for high-rise building, long-span bridge and long tunnel construction. Consequently, the development and optimization of pumping prediction methods are becoming critical issues for the construction industry. However, the development of reasonable and simple prediction tools and measurement techniques is difficult and a challenge of great importance.

As concrete pumping involves complex fluid flow under high pressure in a pipe, predicting its properties requires detailed knowledge of many parameters such as friction, dynamic segregation, mix proportion, coarse aggregate size, mineral admixtures, chemical admixtures, geometry of the pumping circuit, applied pressure, and target flow rate [1–6].

In previous studies on concrete pumping, friction was considered to be the main physical feature [7–10]. Concrete was assumed to slide in a pipe, and the friction-velocity relationship was investigated. Recently, the dynamic segregation was explored, which led to the definition of a lubrication layer, which is a mortar-like layer that forms near the pipe wall [2–6]. Shearing occurs in this layer because of its lower yield stress and plastic viscosity relative to concrete. Friction is no longer assumed to dictate the flow behavior in a pipe. Shearing causes the complex variations in the concrete composition, which affect the rheological properties and flow behavior [11–15].

In addition, from a mixing proportion point of view, several studies have examined the effects of mineral admixtures on the fluidity [16–21], and Blast Furnace Slag (BFS) and Fly Ash (FA) were

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reported to contribute to the increased flowability due to ball bearing effect of particles and densified microstructures as well as the development of higher mechanical properties owing to their latent hydraulic properties and pozzolanic reaction [16,18,19]. Silica Fume (SF), having a very fine particle size, works as a densifying additive for cementitious materials and also affects the flowability of fresh concrete. Zhang et al. [21] reported that the yield stress value of cement paste is generally decreased with the increase of the ultra-fine admixtures quantity added, but the viscosity varies greatly with different types and quantity of ultra-fine admixtures. Ultra-fine limestone, SF, FA and BFS can decrease the viscosity of cement paste, whereas anhydrous gypsum can increase it when the ultra-fine admixtures quantity is smaller than or equal to 15%. The viscosity and the yield stress of cement paste are decreased obviously with the increase of the ultra-fine admixtures quantity added, in which the effect of ultra-fine BFS is the most significant when the ultra-fine admixtures quantity is more than 15%. The viscosity and the yield stress can be decreased by a respective addition of 10% ultra-fine limestone, SF, FA or a single addition of 35% ultra-fine BFS. In other words, mineral admixtures have an effect on the flow properties of cementitious materials, which could influence the pipe flow performance of pumped concrete. Regarding influence of chemical admixtures, Jeong et al. [22] examined the effects of the amount of superplasticizer on the pumping performance and reported that the flow rate was proportional to the dose of superplasticizer, even though its rate of change is different and the pumping performance can be improved by adequately increasing the superplasticizer dosage. Choi et al. [23] examined the effects of coarse aggregate sizes on the pumping performance with three different maximum coarse aggregates, incorporating 10, 20, and 25 mm and reported that a high viscosity was required for the acceptable stability of large-sized aggregate concrete, which results in demanding high pressures and concluded that the maximum coarse aggregate size has a significant effect on concrete pumping.

From a geometrical point of view, Feys et al. [5] evaluated the pressure loss for two different pipe diameters, 100 and 125 mm, with the same concrete and reported that the experimental pressure loss in 100 mm pipes is on average 2.27 times larger than that in 125 mm pipes, i.e., a 20% reduction in pipe diameter could roughly increase the pressure loss by a factor 2.

The concrete flow behavior, especially pressure loss, was reported to be controlled by the flow rate [24,25] and it has a linear relationship in the Poiseuille formula for laminar flow [26] and even for Bingham materials [27]. Kaplan et al. [11,12] reported that the relationship between pressure loss and flow rate is bi-linear, with the inflection point at the pressure loss that identifies a transition from pure plug flow to shearing flow in bulk concrete. Moreover, Mechtcherine et al. [28] and Secrieru et al. [29,30] conducted laboratory tests using special device (Sliper) to investigate the concrete pumpability by analyzing the relationship between pressure loss and flow rate curve and reported that in addition to the rheological properties of the bulk of fresh concrete, the properties of the lubrication layer and the roughness of the pipe-wall significantly affect concrete flow in pipes. Secrieru et al. [31] also investigated Bingham parameters and slippage resistance as parameters related to pumpability. Additionally the correlation between the rheological properties and the pumpability of strain-hardening cement-based composites at various temperatures and times after mixing were analyzed.

Concrete pumping is definitely related to the material properties inside the pipe. The material properties inside the pipe can be represented by the rheological properties of bulk concrete and lubrication layer, which are two representative pumping layers. The pressure loss-flow rate relationship reflects the rheological behavior of concrete. Feys et al. [6] reported that in the case of self-consolidating concrete (SCC), there is a good correlation between the pressure loss and the viscosity of concrete, and the concrete yield stress is the dominant factor for conventional concrete.

However, from the second round-robin tests [32,33], it was confirmed that the rheological parameters from different instruments gave different rheological values for the same materials, even though those instruments represent in fundamental units. This means that the absolute values of the rheological properties for same materials are difficult to determine. Therefore, it is essential to examine the effects of the different measurement systems using different devices on the prediction of the concrete pumping performance.

In this study, to determine the effects of the rheological properties from different measurement systems on predicting the concrete pumping performance, the rheological properties of bulk concrete and lubrication layer were measured separately with different devices using same mix proportions to maintain identical material conditions. The properties of the bulk concrete were measured using two rheometers, ConTect 5 and ICAR. The properties of the lubrication layer were measured using the developed tribometer [3] and Brookfield viscometer using wet-screened mortar [2]. In addition to the rheological properties, a determination of the thickness of the lubrication layer is crucial for predicting the pumping performance in a pipe [2,5,34]. Several studies have examined the effects of the thickness of the lubrication layer and what thickness should be considered when predicting the pumping performance is a challenging but important issue [2,5,34]. Therefore, the variation of the thickness of the lubrication layer depending on the measured rheological properties was also examined.

For the verification, full scale pumping tests were conducted with four different horizontal lengths of a pumping circuit (200 m, 400 m, 600 m, and 1000 m). With measured rheological properties obtained from two different measuring systems for bulk concrete and the lubrication layer, four different combinations cases were investigated and the calculated pumping pressures for each case were compared with the experimentally measured pumping pressures of a full scale test. In addition, with the differently measured rheological properties, the relationship between rheological properties and thickness of the lubrication layer on predicting concrete pumping was verified experimentally with a full scale test.

2. Mechanism on the pipe flow of pumped concrete

2.1. Different methods for measuring the rheological properties inside the pipe

The pumped concrete inside the pipe can be considered two representative pumping layer, bulk concrete and lubrication layer, and the rheological properties of each material contributed mainly to determining the pumping performance. Based on the basic assumption of two layers, two different methods to measure rheological properties of those layers were explored.

In determining the rheological properties of lubrication layer, from a particle migration point of view, when concrete is pumped through the pipe, the migration of sand particles can be neglected compared to the migration of gravel particles and that the lubrication layer could be considered, as a first approximation, to be similar to the constitutive mortar of pumped concrete [2]. This assumption was adapted and the constitutive mortar wet-screened from the fresh concrete and its rheology was measured using a Brookfield viscometer.

In another approach, which was developed in the early 2000's, the lubrication layer properties were reproduced in a tribometer [3,5,34]. This device is almost same with a concrete rheometer,