Construction and Building Materials 61 (2014) 18–23

Contents lists available at ScienceDirect

Construction and Building Materials

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

Effects of an externally imposed electromagnetic field on the formation of a lubrication layer in concrete pumping

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HIGHLIGHTS

- It needs to improve efficiency of concrete pumping in a large scale construction.
- The externally imposed electromagnetic field enhances the pumpability of concrete.
- The properties of the lubrication layer are changed by the electromagnetic field.

ARTICLE INFO

Article history:
Received 13 December 2013
Received in revised form 20 February 2014
Accepted 26 February 2014
Available online 21 March 2014

Keywords:
Pumpability
Lubrication layer
Electromagnetic field
Concrete

ABSTRACT

During concrete pumping, a lubrication layer is formed at the interface between the concrete and the pipe. The pumpability highly depends on the characteristics of this layer. In this study, a method to enhance the pumpability by externally imposing an electromagnetic field on the pipe was suggested and experimentally verified. The electromagnetic field activates the free movement of the water molecules so that the layer is expected to become more slippery. Pumping tests with a 1000 m long pipeline were conducted with and without applying an electromagnetic field. When the electromagnetic field was imposed, the same discharge rate could be obtained with a 30% reduction in the pump pressure, and a 15% increase in the velocity under the same pump pressure was observed. The tests revealed that the imposition of an electromagnetic field was very effective in improving the pumpability.

1. Introduction

Since concrete pumping was first introduced in the 1930s, it has become a commonly used technique to transport fresh concrete for placing in construction sites. Concrete pumping offers notable advantages such as allowing casting in difficult to access locations, reducing casting durations, and allowing continuous concrete casting. However, in the construction of large scale structures such as high-rise buildings, super long bridges, and long-distance tunnels, it is still challenging to transport concrete by pumping because of the limited capacity of existing pumps and inadequate technological solutions to enhance the pumpability through altering the concrete mix.

Various studies [1–13] have indicated that the dominant factor which facilitates the pump is the lubrication layer formed at the interface between the concrete and the wall of the pipe. The existence of this layer was first suggested by Alekseev [5] and Weber [6] and there have since been numerous attempts to estimate its properties. Morinaga [7] also noted that, from a theoretical point of view, when considering only the rheological parameters of the concrete itself, the pumping of concrete would not be possible without the formation of this slippage layer. Sakuta et al. [8] went further and demonstrated that the flow properties of the bulk concrete are irrelevant to the pipe flow of pumped concrete. The only properties that matters in concrete pumping are those related to the ability of the material to form this layer. Jacobsen et al. [9] used colored concretes in a pipe to directly observe their flow profiles. The results demonstrated the existence of a high velocity and paste rich zone at the vicinity of the wall of the pipe. A study by Kaplan et al. [10] on predicting pumping performance demonstrated that

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http://dx.doi.org/10.1016/j.conbuildmat.2014.02.071
0950-0618/

the lubrication layer is a major factor in facilitating concrete pumping, because the layer has a significantly lower viscosity and yield stress than concrete. They also developed a test instrument called a tribometer that can measure the friction stress at the wall of the pipe. Choi et al. [11] tried to directly measure the velocity of lubrication layer for full size pumping circuits using an ultrasonic velocity profiler (UVP) and Jo et al. [12] and Choi et al. [13] simulated the formation of the lubrication layer in the concrete flow inside the pipe considering the shear-induced particle migration. As briefly summarized herein, most studies on concrete pumping have focused on evaluation of the lubrication layer to estimate the pumpability of concrete.

The basic goal of the present study is to improve concrete pumpability by manipulating and controlling the properties of the lubrication layer. One possible method to accomplish this is to introduce an electromagnetic field to the pipe when concrete is being pumped. During concrete pumping, a redistribution of particles occurs in the vicinity of the pipe wall [12–16]. As a result, the lubrication layer can therefore be considered as a paste rich zone. This layer consists of water, cement, and fine sand. Water content in this layer has of course a significant influence on the properties of the layer. Various studies [17–22] have shown that usage of magnetic field treated water in concrete field can increase the workability, accelerate the hydration reaction, increase the compressive strength, and improve the impermeability and freeze/thaw resistance. Through the magnetic treatment on water, the characteristic of concrete could be improved. When applying same principle to concrete pumping, stimulating the movement of water molecules within the layer by externally imposing an electromagnetic field on the outer surface of the pipe could be an effective means of improving the pumpability.

The objective of this study is to investigate the effects of an externally imposed electromagnetic field on the formation of the lubrication layer in an experimental way. Full-scale pumping tests with a 1000 m long pipeline were performed with three different concrete mixes according to the imposition of an electromagnetic field. A special electronic control device called a Fluid-Liner [23,24] was mounted on the pipe in front of the pump to induce the electromagnetic field. The pressures inside the pipe and the flow rates were measured during pumping concrete. In addition, the velocity profile near the wall of the pipe was observed with a special sensor using ultrasonic waves [11,13]. Based on the test results, the effects of an electromagnetic field on the lubrication layer were quantitatively analyzed.

2. Activation of water molecule movement due to electromagnetic field

When an electromagnetic field is imposed to the outer surface of the pipe, water existing in the lubrication layer can be directly affected and activated. Water is a polar substance, and water molecules tend to be attracted to each other by hydrogen bonding and form clusters, as illustrated in Fig. 1(a) [20,25]. The associations and disassociations of water molecules are in thermodynamic equilibrium. In general, each cluster contains about 100 water molecules at normal temperature [26,27]. Under a magnetic field, magnetic force can break apart water clusters into single molecules or smaller clusters, as shown in Fig. 1(b), thereby increasing the activity of water [17–21]. For water with the same or close ionic composition, as the cluster size of water becomes smaller, the activity of the water becomes accordingly higher.

Yu et al. [21] demonstrated that a decrease of the peak width of NMR (Nuclear Magnetic Resonance) spectroscopy of water proves that the molecule clusters of water have been reduced by electromagnetic treatment. Accordingly, the activity of the water after

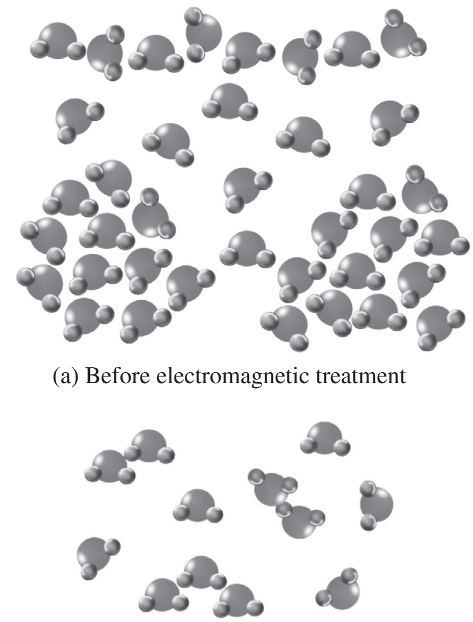

Fig. 1. Schematic structure of the molecule clusters of water.

electromagnetic treatment becomes higher than that of normal water. Wang et al. [28] pointed out that an electromagnetic field affects water hydrogen bonding and brings about structural and charge changes of ions in water. Therefore, in the present study, by inducing an electromagnetic field on the lubrication layer, which is significantly controlled by the water present within it, the properties of this layer could be manipulated, leading to improve concrete pumpability.

3. Experimental program

3.1. Concrete mixes

Three different concrete mixes were prepared for this study. The mixture proportions are listed in Table 1. The cement was CEM I 52.5 N with a density of 3150 kg/m^3. The sand was natural river sand with a density of 2590 kg/m^3 and a fineness modulus of 2.81. Sand particles size ranged from 0.08 to 5 mm in size with a water absorption capacity of 2.43%. The coarse aggregate was a limestone aggregate material with a water absorption capacity of 0.8%, a density of 2610 kg/m^3 and the fineness modulus of 6.72. The amount of mixing water was corrected to take into account the water absorbed by the sand and coarse aggregates. A polycarboxylate-based high-range water-reducing admixture (HRWRA) was used. As listed in Table 1, its dosage, marked as % HRWRA, meaning the percentage of admixture relative to the binder content (in weight), was adjusted to obtain the same slump flow.

To carry out pumping tests in real size pumping circuits, each concrete mix was produced in a batch of 2 m^3 at a time and dumped into the total 6 m^3 mixer and delivered by a ready-mix concrete company. The mixing procedure was as follows:

Table 1
Mixture proportions.

Materials	Design strength		
Name of the series	C40	C50	C60
Cement CEM I 52.5 N, kg/m^3	201	225	257
Fly ash class *F*, kg/m^3	45	50	57
Blast furnace slag, kg/m^3	201	225	257
W/*B* ratio	0.38	0.33	0.28
Sand, kg/m^3	768	736	713
Coarse aggregate, kg/m^3	873	871	844
Polycarboxylate-based HRWRA (%)	0.8	0.9	1.0
Slump flow, mm	600 ± 20	620 ± 20	620 ± 20