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Shear-thickening behavior of high-performance cement grouts — Influencing mix-design parameters

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ABSTRACT

Rheology of concrete is of great importance to its flow performance, placement and consolidation. A full understanding of fresh concrete flow behavior can be achieved through a good understanding of paste rheology. Cement pastes exhibit a complex rheological behavior affected by several physical and chemical factors, including water-to-cement ratio (w/c), high-range water-reducer (HRWR) type and dosage, and cement characteristics. An experimental investigation was carried out to evaluate the effect of w/c, HRWR–cement combinations, and supplementary cementitious materials (SCM) on the pseudoplastic behavior of high-performance cement grouts. Grout mixtures proportioned with w/c of 0.30, 0.33, 0.36, and 0.40, various cement–HRWR combinations, and cement substitutions by 8% silica fume were investigated. The incorporation of HRWR can lower the yield stress of mixtures, thus enhancing deformability, while silica fume improves mechanical and durability performances.

High-performance structural grouts are shown to exhibit shear-thickening behavior at low w/c and shear-thinning behavior at relatively higher w/c. Mixtures made with polycarboxylate HRWR acting by steric effect exhibited greater shear-thickening behavior compared to those made with polynaphthalene sulfonate-based HRWR acting by electrostatic effect. The paper discusses the effect of mixture parameters on non–linear rheological behavior of various grout mixtures prepared with different w/c, HRWR–cement combinations, and silica fume.

1. Introduction

Fresh concrete is a solid suspension of aggregate in cement paste. Investigations of cement paste rheology are motivated by the need to understand flow properties of concrete to secure good flow performance, placement, and consolidation. In addition, rheology can be used as a design parameter of high-performance concrete to tailor appropriate flow curves that satisfy the various requirements, including pumping pressure and distance, free fall of concrete into formwork, required stability level after placement and consolidation during the dormant period. Development of self-consolidating concrete (SCC), characterized by high deformability to facilitate casting and ensure adequate mechanical and structural performance, is an example of the tremendous benefit of using rheology as a mix design tool. The incorporation of HRWR in SCC to reduce the yield stress can result in enhancing deformability of mixtures [1,2].

Cement paste may be considered as a flocculent system due to the effects of Van der Waals attraction and hydrodynamic forces, as well as chemical reactions, resulting in a complex rheological behavior affected by several physical and chemical factors [3–6]. The flow behavior of cement paste is dominated by its solid concentration, size distribution of cement grains, chemical composition of cement, temperature, mixing energy, and the presence of HRWR. Such behavior is further complicated by shear history, the use of low w/c, and in some cases, supplementary cementitious materials (SCM) incorporated to enhance fresh and hardened properties. Rheological behavior of low w/c mixtures, is greatly influenced by cement–HRWR interaction and dispersing mechanism of HRWR.

The dispersing efficiency of an HRWR is mainly related to the chemical effects that are inherent functions of the reactive nature of cement particles. This may include preferential adsorption, chemisorptions, and chemical reactions to form new hydrate phases [7,8]. The dispersing mechanisms induced by an HRWR can be a combination of both electrostatic and steric repulsive forces [7,9–13]. Anderson has suggested that high molecular weight polymers lead to additional short-range forces, while low molecular weight polymers usually exhibit lower fluidity and poor fluidity-retention with time [14,15]. Uchikawa et al. reported that electrostatic forces play a major role in the dispersing mechanism of polynaphthalene sulfonate condensate (PNS) superplasticizers, while steric forces are dominant for a copolymer of acrylic acid with acrylic ester [16].

High-performance cement grouts incorporating a new generation of HRWR and viscosity modifying admixtures (VMA) exhibit a higher degree of pseudoplastic properties compared to conventional grouts [17–25]. Structural cement grouts proportioned with 0.40 w/c, different VMA–HRWR combinations, and various SCM, including silica fume, blast-furnace slag, and fly ash, exhibited a shear thinning behavior even

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