EFFECTS OF EXTERNAL MAGNETIC FIELD ON STRUCTURAL EVOLUTION OF CEMENT PASTE WITH NANO-FE3O4

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Abstract

Pumping and formwork casting are indispensable processes of modern engineering applications of high performance concrete. However, there always exists a contradiction in the requirements of structuration rate of fresh concrete during the pumping and casting operations. For the same concrete mixture, actively controlling the rheology and stiffness of fresh concrete by applying external magnetic fields would be a potential solution for the contradicting requirements. In this paper, the structural evolution of cementitious paste containing nano-Fe_3O_4 particles under various external magnetic fields are illustrated. Under magnetic fields with high magnetic flux densities, the viscous-liquid behavior dominated the elastic-solid behavior at the first few seconds, while the solid-like behavior became more dominant with elapsed time. Higher magnetic field strengths resulted in higher percolation time and lower phase angle at equilibrium state.

Keywords: Cement paste; Magnetic field; Structural evolution; Viscoelastic behavior

1. INTRODUCTION

With the widely use of mineral additions and chemical admixtures, the pumping operation becomes an indispensable part of modern engineering applications of high performance concrete (HPC) and even ultra-high performance concrete (UHPC). Many researchers have focused on the characterization of flow regime inside the pipe and the prediction of pumping pressure [1-3]. However, there are still some challenges, such as the pumping of UHPC, the effects of bends and reducers, and the changes of concrete properties during pumping [4, 5]. Most importantly, the thixotropic structure build-up could be a major problem in resuming pumping operations after short interruptions. However, a higher structuration rate of fresh concrete was beneficial for reducing the formwork pressure at the casting process [6, 7]. As a result, there has always been a contradiction in the requirements of structuration rate for fresh concrete during the pumping and casting operations. Actively controlling the rheology and stiffness of fresh concrete would make the pumping and casting processes more reliable and smarter. In the present paper, the influences of external magnetic fields on the structural evolution of cementitious paste containing nano-Fe_3O_4 particles are presented. This paper provides a preliminary understanding on the effects of external magnetic fields on the structure formation of cementitious pastes at the early ages.

2. STORAGE MODULUS

The elastic and viscous properties, experimentally obtained by means of small amplitude oscillatory shear (SAOS), provide a useful insight for the understanding of the structural evolution of samples without disturbing the contacts between particles [8-10]. The development of storage modulus of cementitious paste (w/c=0.4) with 3% nano-Fe_3O_4 particles under various magnetic fields are shown in Fig. 1. In the absence of magnetic fields, the storage modulus of pure cement paste gradually increased because of the flocculation, thixotropy and slight hydration reactions [11, 12]. The addition of 3% nano-Fe_3O_4 particles significantly increased the storage modulus of cement paste by 11 times after 5 minutes of magnetizing. This can be attributed to the high water-requirements of nano-Fe_3O_4 particles with ultra-high specific surface area. Besides, the nano-Fe_3O_4 particles have a strong tendency to agglomerate due to their high magnetic properties [13, 14], which should also be responsible for the improvement of solid-like properties. The storage modulus also gradually increased with the increase of magnetic field strengths.

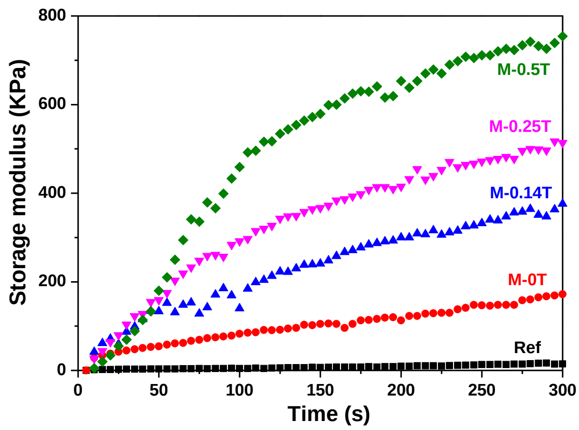

Figure 1: Effects of external magnetic fields on the evolution of storage modulus

3. LOSS MODULUS

The evolution of loss modulus with magnetizing time is shown in Fig. 2. Comparing with the results of storage modulus, it can be seen that the loss modulus was significantly smaller than the storage modulus at the same magnetizing time. The loss modulus obtained at higher magnetic field strength were more scattered, but stronger magnetic fields still resulted in higher loss modulus. Without the magnetic field, the loss modulus gradually increased with elapsed time, regardless of the mixture proportions. However, at the presence of magnetic field, the loss modulus of cement paste containing nano-Fe_3O_4 particles increased first and then gradually decreased, and the critical time corresponding to the highest loss modulus was gradually increased with the magnetic field strength. This indicates that the most pronounced viscous liquid behavior could be obtained after the application of magnetic field. With the increasing magnetizing time, the elastic solid behavior gradually dominated the liquid-like property.

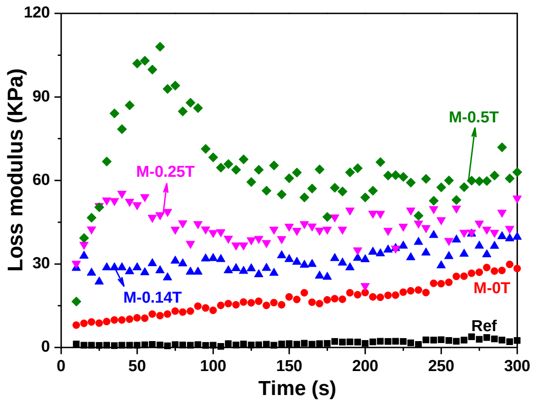

Figure 2: Effects of external magnetic fields on the evolution of loss modulus

4. PHASE ANGLE

The phase angle (δ) is used to describe the phase shift between the applied stress and resultant strain, which can be calculated as $\tan^{-1}$ (G''/G'). The phase angle of cement paste as a function of time under various magnetic fields is shown in Fig. 3. As expected, the phase angle was significantly decreased and then stabilized, reflecting the transition from liquid behavior to elastic behavior. The time where the value of phase angle starts to stabilize can be defined as the percolation time [15], which can be used to describe the time for colloidal particles to reach their equilibrium positions. It can be seen that the percolation time gradually increased with the increase of magnetic field strength. For example, in the case of cement paste with 3% nano-Fe_3O_4, the percolation time was about 20 s and 100 s under a magnetic field of 0 T and 0.5 T, respectively. Besides, higher final structure strengths were obtained at higher magnetic fields. In other words, it will need longer time for the magnetic particles to reach their favorable positions at higher magnetic fields.

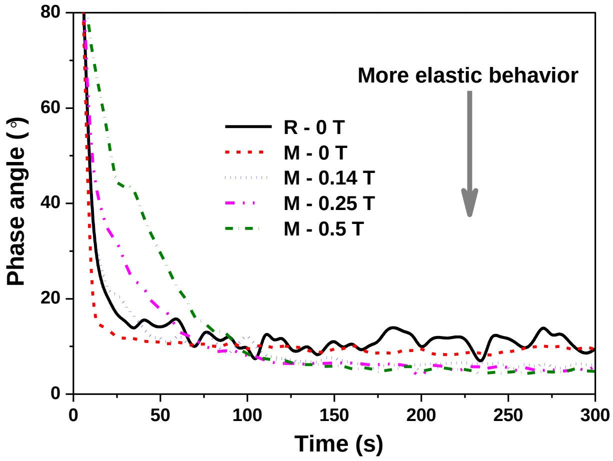

Figure 3: Phase angle as a function of time under various magnetic fields

5. CONCLUSIONS

- The storage and loss moduli increased with the addition of nano-Fe_3O_4 particles.
- Higher magnetic field strengths resulted in higher storage modulus and percolation time, as well as lower phase angles at equilibrium state.
- The loss modulus increased first and then gradually decreased under magnetic fields, and the critical time was directly proportional to the magnetic field strength.

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