Construction and Building Materials 55 (2014) 57–62

Contents lists available at ScienceDirect

Construction and Building Materials

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

Improvement of autogenous shrinkage measurement for cement paste at very early age: Corrugated tube method using non-contact sensors

Peng Gao, Tongsheng Zhang, Ruifeng Luo, Jiangxiong Wei, Qijun Yu *

School of Materials Science and Engineering, South China University of Technology, 510640 Guangzhou, People's Republic of China

HIGHLIGHTS

- Test methods for autogenous shrinkage of cement paste are reviewed.
- Few methods are able to measure the very early autogenous shrinkage of cement paste.
- A non-contact corrugated tube system was designed.
- Results obtained by the designed system show superior accuracy and repeatability.

ARTICLE INFO

Article history:
Received 21 July 2013
Received in revised form 16 December 2013
Accepted 24 December 2013
Available online 2 February 2014

Keywords:
Autogenous shrinkage
Corrugated tube method
Non-contact sensor
Repeatability

ABSTRACT

Test methods for the measurement of autogenous shrinkage of cement paste were reviewed, and it is found that few methods can precisely determine the autogenous shrinkage of cement paste at very early age. Therefore, the corrugated tube method was improved by using non-contact linear variable differential transformer (LVDT) sensor for measuring the autogenous shrinkage of cement paste at very early age. The experimental results show that the transformation ratio of the volume deformation to length change for the designed non-contact system can be as high as 0.97, which gives a significant improvement compared to that for the contact system (0.87). Compared to the contact system, the designed non-contact system also has an improved repeatability: the typical standard deviations reach about 50 μm/m and 10 μm/m before and after setting, respectively.

1. Introduction

1.1. Autogenous shrinkage

Autogenous shrinkage is generally defined as "the unrestrained, bulk deformation that occurs when cement-based materials are sealed and no loss of moisture or mass occurs with the external environment under a constant temperature" [1]. It mainly attributes to the chemical shrinkage and self-desiccation shrinkage. Chemical shrinkage, also known as Le Chatelier's contraction, is a continuous feature of cement-based materials during the hydration process, since hydration products occupy less absolute volume than reactants (water and cement) [1,2]. When stiff skeleton structure is formed in cement paste during the hydration process, internal voids form in the matrix due to chemical shrinkage, leading to the formation of water–air menisci and continuous reduction of the internal relative humidity (RH) [3,4]. Consequently, tensile stress is generated in the pore solution, resulting in the self-desiccation shrinkage [5].

Chemical shrinkage is an absolute volume change (internal), and autogenous shrinkage is an apparent volume change (external) [2,6]. The schematic diagrams of chemical shrinkage and self-desiccation shrinkage are presented in Fig. 1. Even hydration of only one cement particle can result in chemical shrinkage (Fig. 1(a)). Before the formation of stiff skeleton structure, autogenous shrinkage of cement paste is equal to the sum of chemical shrinkage of individual cement particle. Self-desiccation shrinkage is an apparent shrinkage and cannot exist without the formation of voids in cement paste (Fig. 1(b)). After the formation of stiff skeleton structure, self-desiccation shrinkage is considered as the main part of autogenous shrinkage. During the two periods of hydration process, chemical shrinkage is always a fundamental factor of autogenous shrinkage.

Autogenous shrinkage is increasingly concerned for the sake of maintaining durable civil engineering buildings and constructions using cement-based materials with a low water to cement ratio (w/c) and can be divided into two parts: shrinkage at early age (the first 24 h) and shrinkage in long term (after 24 h) [7]. The former, accounting for the main proportion of ultimate shrinkage, is the main factor inducing the cracking of cement-based constructions [8,9]. Therefore, the investigation on the autogenous

* Corresponding author. Tel./fax: +86 020 87114233.
E-mail address: concyuq@scut.edu.cn (Q. Yu).

0950-0618/$ - see front matter
http://dx.doi.org/10.1016/j.conbuildmat.2013.12.086

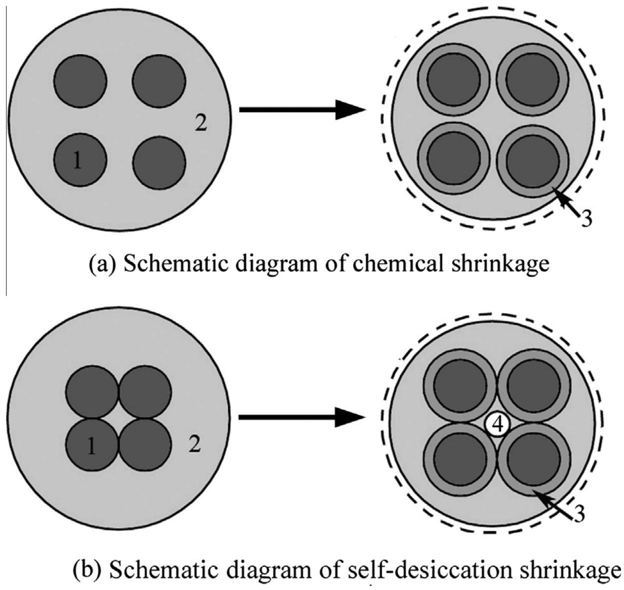

Fig. 1. Schematic diagram of chemical shrinkage and self-desiccation shrinkage. (1) Anhydrous cement, (2) pore solution, (3) hydration products, and (4) air void.

shrinkage of cement-based materials at early age is very important [10]. However, the precise measurement is the major problem as reported [11]. Following is the literature review on the measurement methods for autogenous shrinkage of cement paste and especially on the measurement at very early age.

1.2. Test methods for autogenous shrinkage of cement paste

Measurement methods for determining the autogenous shrinkage of cement paste can be classified into volumetric and linear methods [4,7,12,13], as shown in Fig. 2. In the volumetric method, cement paste is introduced into a membrane (condom was normally used) and cured under isothermal water (Fig. 2(a)). The volume change of external water or buoyancy change of cement paste is recorded to represent the autogenous shrinkage. The main advantage of this method is that it can measure the initial autogenous shrinkage of cement paste immediately after mixing [13]. However, its precision is influenced by many factors, e.g. the bleeding effect and the membrane permeability. The bleeding water accumulated on the surface of cement paste before setting can be re-absorbed in the sample, causing additional shrinkage [13,14]. Bouasker et al. [11] proposed a dynamic system by rotating the sample during the whole testing period to eliminate the bleeding effect. However, the fluctuation of the measured data was also resulted from the rotation. In terms of the influence of membrane permeability, water can continuously transport into the pore solution of cement paste through the membrane after immersing, increasing the buoyancy of cement paste and causing a significant error. Lura and Jensen [15] reduced this error by immersing the sample into paraffin oil instead of water. However, Bouasker et al. [16] indicated that the error cannot be perfectly eliminated, because paraffin oil can be absorbed on the membrane. Additionally, the volumetric method is not suitable to measure the autogenous shrinkage for concrete, because the membrane can be easily broken by the sharp aggregate.

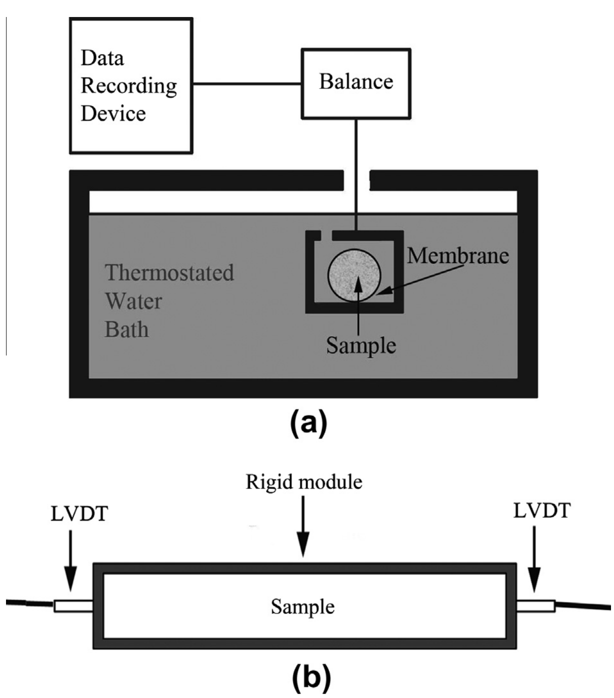

Fig. 2. Typical test methods for the autogenous shrinkage of cement paste. (a) Volumetric method, and (b) linear method.

In the linear method, cement paste is commonly cast in a rigid module with a low friction (Fig. 2(b)) [10,11,17,18]. This method can also be classified into two categories: horizontal and vertical methods. In both methods, displacement sensors, e.g. linear variable differential transformers (LVDT) are commonly used to record the length change of cement paste. The main shortage of the horizontal method is that it cannot precisely measure the autogenous shrinkage of cement paste at plastic stage, because the length change cannot represent the volume deformation during this period [13]. In vertical method, although the autogenous shrinkage can be immediately measured after casting, the error also occurs due to the influence of gravity force [14].

Jensen and Hansen [12] proposed a linear method to determine the autogenous shrinkage of cement paste at early age by using corrugated tubes, as shown in Fig. 3. The corrugated tubes transform the volume deformation into length change before the formation of stiff skeleton structure, which solves the main drawback of the previous reported linear methods. This method was widely used to investigate the early age autogenous shrinkage of cement-based materials [13,15,16], and a standard test method for autogenous strain of cement paste and mortar in terms of corrugated tube method was published by American Society for Testing Materials [19].

However, considerable errors are caused by the stress between the contact sensors and corrugated tube before the formation of

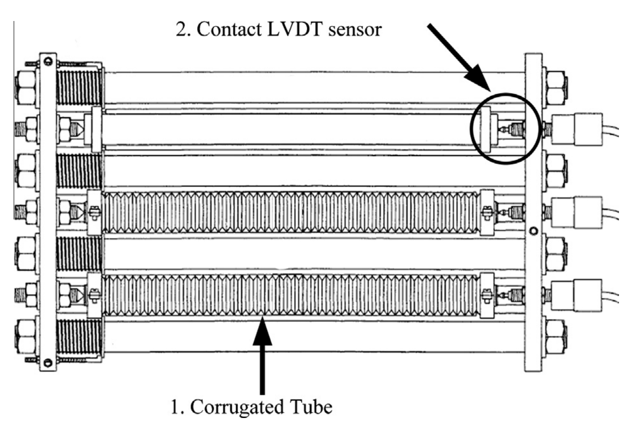

Fig. 3. Contact corrugated tube method proposed by Jensen and Hansen [12].