Construction and Building Materials 74 (2015) 93–101

Contents lists available at ScienceDirect

Construction and Building Materials

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

An innovative test apparatus for oil well cement: In-situ measurement of chemical shrinkage and tensile strength

Xueyu Pang [a,*], Christian Meyer [b], Gary P. Funkhouser [a], Robert Darbe [a]

[a] *Halliburton, 3000 N Sam Houston Pkwy E, Houston, TX 77032, USA*
[b] *Department of Civil Engineering and Engineering Mechanics, Columbia University, New York, NY 10027, USA*

HIGHLIGHTS

- Cement chemical shrinkage under pressure can be measured by an injection pump.
- Chemical shrinkage increases with increasing temperature during early stage.
- Curing pressure up to 13 MPa has relatively little effect on chemical shrinkage.
- Hydraulic fracture method may be used to obtain the in-situ strength of well cement.

ARTICLE INFO

Article history:
Received 12 July 2014
Received in revised form 29 September 2014
Accepted 14 October 2014
Available online 3 November 2014

Keywords:
Temperature
Pressure
Tensile strength
Oil well cement
Downhole conditions
Chemical shrinkage

ABSTRACT

An innovative apparatus has been developed in this study to cure and test oil well cement specimens under simulated down-hole conditions with high temperature and high pressure. The test apparatus can be used to monitor cement chemical shrinkage in real time and measure fluid pressure tensile strength under in-situ conditions, i.e. without changing the temperature or releasing the pressure of the specimen. This paper describes the basic principles of this newly developed test method and detailed configuration of the test apparatus. A series of tests were performed on different classes of oil well cement to evaluate the functionality of the test device. Specimens in groups of four were cured at temperatures ranging from 24 to 60 °C and pressures ranging from 0.69 to 13.1 MPa.

1. Introduction

Cementing is one of the most important phases of oil or gas well construction, the purpose of which is to create a cement sheath in the annulus between the steel casing and the wellbore. The cement sheath primarily acts as a seal to isolate different zones of the formations and prevent the migration of hydrocarbons or water from one layer to another. In addition, it also serves to protect the casing from corrosion as well as from shock loads due to further drilling [1]. As both temperature and pressure increase with the depth of the wellbore, oil well cements are subject to wide ranges of temperature and pressure. Traditional testing methods do not allow the properties of cement to be determined in-situ, i.e. under conditions of high temperature and high pressure. Therefore, specimens cured under simulated down-hole conditions (or actual field conditions) have to be tested after they had been returned to ambient temperature and pressure [2–7]. If the specimens are damaged with the changes of temperature and pressure, traditional test results can be unreliable. The newly developed test apparatus in this study allows determining the fluid pressure tensile strength of set oil well cement specimens under simulated in-situ temperature and pressure conditions, without exposing the specimen to the ambient condition. The current study only focuses on validating the new test concept, rather than simulating the most severe down-hole conditions in terms of the possible temperature and pressure range encountered.

The concept of fluid pressure testing of concrete originated almost a century ago, when Bridgman [8] reported that a cylindrical specimen appeared to have a tensile fracture transverse to its axis if appropriate fluid pressure was applied to its bare curved surface. Lile et al. [9] used a somewhat similar approach to obtain

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* Corresponding author.
E-mail address: Xueyu.Pang@halliburton.com (X. Pang).

http://dx.doi.org/10.1016/j.conbuildmat.2014.10.025
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the tensile strength of a hydrating cement paste at the age of several hours, by pumping water into the cement paste cast in a cylindrical cell through a pipe embedded in the specimen. In a typical Bridgman-type test, a cylindrical concrete specimen is placed in an open-ended steel jacket sealed with O-rings, Fig. 1(a). The specimen is fractured by gradually increasing the fluid pressure on the curved surface of the specimen. This particular test method opened an opportunity for in-situ measurement of the tensile strength of cement paste cured at high pressures. Based on the same concept, a cylindrical specimen cured under hydrostatic pressure may be tested by increasing the pressure difference between the annular zone and the end zones, Fig. 1(b). However, just like other indirect methods, the tensile strength obtained from fluid pressure tests may deviate from that obtained from direct tension tests. The dependence of tensile strength on specific testing methods will be further discussed in Section 2.2. For comparison purpose, the influences of curing temperature and pressure on both in-situ fluid pressure tensile strength and traditionally determined tensile strength were investigated.

In addition to giving in-situ tensile strength, the apparatus (pressure cells) developed in this study also provides a new way of continuously measuring chemical shrinkage of cement under simulated downhole conditions with high temperature and high pressure. Cement chemical shrinkage is known to be strongly related to its degree of hydration [10–13]. The continuous measurement obtained with the new test apparatus allows the determination of the rate of hydration in situ at different temperatures and pressures, which can be used to study the mechanism of cement hydration [14,15]. Before introducing details of the new test apparatus, it is necessary to review the current practices of measuring the chemical shrinkage and tensile strength of cement-based materials such that the new test method can be compared with conventional ones.

2. Literature review

2.1. Chemical shrinkage tests

Under atmospheric pressure, chemical shrinkage is measured by monitoring either the volume or the weight of the water uptake of a thin layer of cement paste placed in a flask or a glass vial (ASTM C1608 [16]). Despite the apparently simple principle, there are experimental difficulties that may result in unreliable results. For example, the test involves adding a significant amount of water on top of a thin specimen (<10 mm) to keep it saturated. A recent study has shown that the quantity and the composition of the surface water have a significant impact on test results [17]. It is also well known that, when the same measuring device was used, increasing specimen thickness usually caused a reduction in chemical shrinkage at later ages (>15 h) [12,17,18]. This thickness effect may be explained by two hypotheses: (1) the reduction in the permeability of the sample might prevent surface water from filling all internal pores in the thicker samples (capillary porosity depercolation); (2) a larger fraction of the thinner sample is diluted by the surface water, resulting in a faster hydration rate at later ages. For the same amount of alite (the main composition of Portland cement) paste, Costoya [12] found that using a small diameter device with less surface water (cylindrical flask) systematically gave a higher chemical shrinkage than using a large diameter device with more surface water (Erlenmeyer flask) even though the former generated a much thicker specimen. The author also reported that chemical shrinkage measured with the cylindrical flask was the same as that measured with a set ground paste specimen for a period exceeding 250 h. Therefore, for traditional chemical shrinkage tests, the effects of surface water might have a stronger effect on test results than the thickness of the specimen. Costoya [12] also found massive precipitations of large portlandite

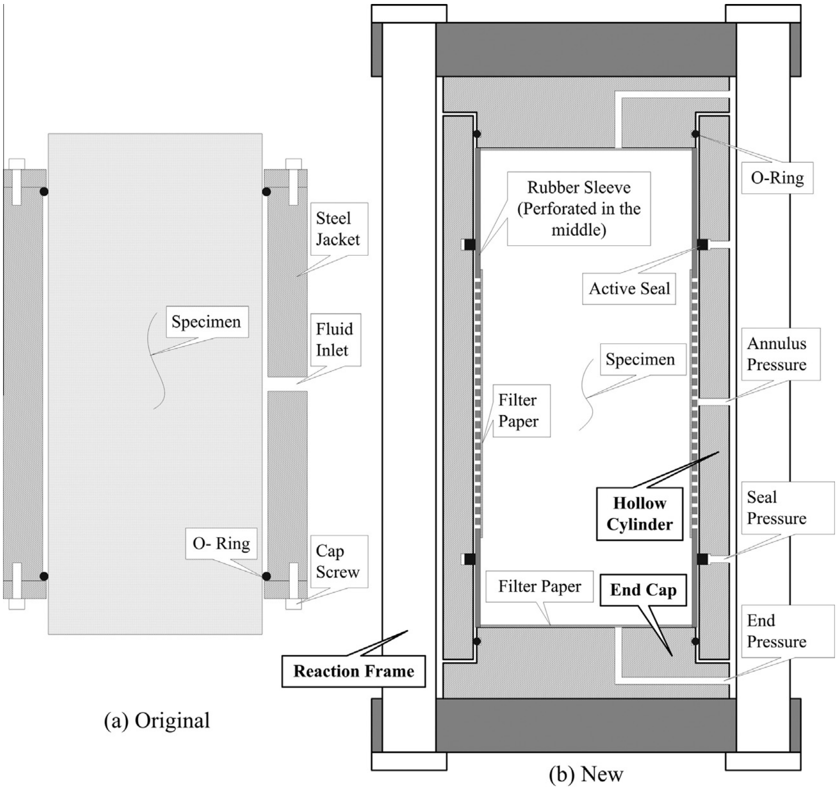

Fig. 1. Sketches of apparatuses used for fluid pressure tests (not to scale).