Report on Factors Affecting Shrinkage and Creep of Hardened Concrete

Reported by ACI Committee 209

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This guide describes the effects of numerous variables on shrinkage and creep of hardened concrete, including mixture proportions, environment, design, and construction. This document is aimed at designers who wish to gain further information about factors changing shrinkage and creep but does not include information on the prediction of shrinkage and creep or structural design issues associated with shrinkage and creep.

Keywords: creep; drying shrinkage; strain.

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CHAPTER 1—INTRODUCTION

1.1—Scope

Factors affecting shrinkage and creep of hardened concrete are presented to enable those involved in the evaluation and formulation of concrete mixtures to determine the effects of these factors. Section 1.2 of Chapter 1 defines terms used by those evaluating shrinkage and creep, while Chapters 2 and 3 describe effects of various factors on shrinkage and creep. This document does not include information on the prediction of shrinkage and creep or structural design issues associated with shrinkage and creep.

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This document is not intended as a primary reference source for those studying shrinkage and creep; rather, it is aimed at designers who wish to gain further understanding of the effects of materials being used. This document also provides references that provide direction for those wishing to seek additional information about shrinkage and creep.

1.2—Terminology and range of values of strains

To discuss shrinkage and creep, it is important to define the following terms:

- Total strain;
- Shrinkage;
- Autogenous shrinkage;
- Drying shrinkage;
- Carbonation shrinkage;
- Swelling;
- Load-induced strain;
- Initial strain at loading or nominal elastic strain;
- Creep strain;
- Basic creep;
- Drying creep;
- Compliance;
- Specific creep; and
- Creep coefficient.

Various terms are shown in Fig. 1.1 and are described in detail below, together with an indication of typical value ranges. The values of total strain, shrinkage, and creep are time-dependent. A thorough discussion of definitions, basic assumptions, and standard test methods for creep and shrinkage can be found in the references (RILEM TC 107-CSP 1998; Carreira and Burg 2000).

Shrinkage and creep may occur in three dimensions; however, most research suggests that total strain, shrinkage, and creep occur in each dimension independently. Thus, changes in length will be consistently used throughout this document, rather than changes in volume.

1.2.1 *Total strain*—Total strain is the total change in length per unit length measured on a concrete specimen subjected to a sustained constant load at uniform temperature. As shown in Fig. 1.1, total strain is the sum of shrinkage and load-induced strain.

1.2.2 *Shrinkage*—Shrinkage is the strain measured on a load-free concrete specimen.

Shrinkage does not include changes in length due to temperature variations, but depends on the environment and on the configuration and size of the specimen. Shrinkage strain is usually measured by casting companion load-free specimens identical to the loaded concrete specimens used to measure the total strain. These companion specimens are cast from the same concrete batch, have the same dimensions, and are stored in the same environment as the loaded concrete specimens.

Shrinkage values are given as dimensionless strains (length change over a given length) expressed as percent, mm/mm, or in./in. It is common to describe shrinkage in microstrain or millionths, as the value of strain $\times 10^6$. Thus, 1000 microstrain is equivalent to 1×10^{-3} mm/mm.

Values of long-term concrete shrinkage are typically between 200 and 800 $\times 10^{-6}$ mm/mm, (200 to 800 microstrain) (Zia, Ahmad, and Leming 1997) and mortar shrinkage typically between 800 and 2000 $\times 10^{-6}$ mm/mm (800 and 2000 microstrain) (Heath and Roesler 1999). Cement paste

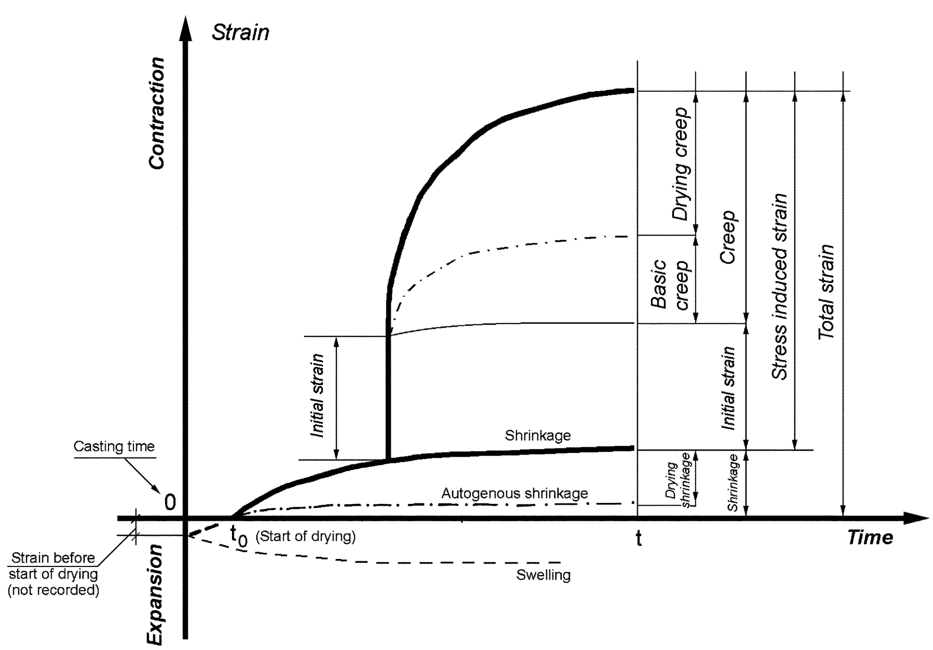

Fig. 1.1—Relationship between various measured and derived strain values. The figure shows that the concrete undergoes autogenous shrinkage before drying. Once drying commences at time t_0, drying shrinkage occurs. Upon loading, both drying and basic creep occurs in the drying specimen.

shrinkage values are typically between 2000 and 6000 × 10^{-6} mm/mm (2000 and 6000 microstrain) (Feldman 1969).

1.2.3 *Autogenous shrinkage*—The shrinkage occurring in the absence of moisture exchange (as in a sealed concrete specimen) due to the hydration reactions taking place inside the cement matrix is termed autogenous shrinkage. Less commonly, it is termed "basic shrinkage" or "chemical shrinkage." Autogenous shrinkage was almost never considered as a factor in research on shrinkage and creep before 1990, and it has become a greater factor with the increased use of high-performance concrete. Factors affecting, and the prediction of autogenous shrinkage, are outside the scope of this report. As development of research continues in this area, ACI Committee 209 will present additional information.

Autogenous shrinkage is usually small for many normal compressive strength concretes and can usually be neglected. For concrete with water-cement ratios (w/c) less than 0.40, however, autogenous shrinkage may be a significant component of the total measured shrinkage (Tazawa 1999).

1.2.4 *Drying shrinkage*—Shrinkage occurring in a specimen that is exposed to the environment and allowed to dry is called drying shrinkage. For normal-strength concrete, it is usually assumed that the entire shrinkage strain is from drying shrinkage, and any contribution from autogenous shrinkage is neglected. Because drying shrinkage involves moisture movement through the material and moisture loss, drying shrinkage depends on the size and shape of the specimen.

Due to the relationship of drying shrinkage to water loss, it may be expected to reach a final value; although, this is difficult to be confirmed experimentally due to the long duration of the drying process in normal size specimens (RILEM TC 107 1995; Al-Manaseer, Espion, and Ulm 1999; Bazant 1999). A final value has been documented for specimens of hardened cement paste thin enough to dry to an equilibrium water content (Wittman et al. 1987).

1.2.5 *Carbonation shrinkage*—Carbonation shrinkage is caused by the reaction of the calcium hydroxide within the cement matrix with carbon dioxide in the atmosphere. Factors affecting, and the prediction of carbonation shrinkage, are outside the scope of this report.

1.2.6 *Plastic shrinkage*—Plastic shrinkage is defined by ACI 116R as the shrinkage that takes place before cement paste, mortar, grout, or concrete sets. Plastic shrinkage is outside the scope of this report.

1.2.7 *Swelling*—When concrete is placed in water it swells, which has been attributed to reduced capillary forces within the concrete (Kovler 1996). Few research studies have closely recorded the magnitude of swelling and studied the factors affecting the magnitude of this phenomenon. The expansion strain due to swelling is approximately 100 × 10^{-6} mm/mm (100 microstrain) (McDonald 1990).

1.2.8 *Load-induced strain*—Load-induced strain is the time-dependent strain due to a constant sustained load applied at the age t'. Experimentally, it is obtained by subtracting from the total strain the shrinkage strain measured on load-free companion specimens with the same size and shape as the loaded specimens and placed in the same environment. The load-induced strain is frequently subdivided into an initial strain and a creep strain. The initial and creep strain components should be defined consistently so that their sum corresponds to the appropriate load-induced strain (CEB 1993; RILEM TC 107 1995; Bazant and Baweja 2000; Carreira and Burg 2000).

1.2.9 *Initial strain at loading or nominal elastic strain*—The short-term strain at the moment of loading is termed initial strain and is frequently considered as a nominal elastic strain as it contains creep that occurs during the time taken to measure the strain. It is dependent on the duration of the load application and strain reading procedures. The separation of this initial component of the load-induced strain is made for convenience, and it may be determined using standardized procedures for the experimental determination of a static elastic modulus (corresponding to the strain in a short interval after load application) (CEB 1993; RILEM TC 107-CSP 1998; Bazant and Baweja 2000; Carreira and Burg 2000). ASTM C 469 is often used to determine this value. In this test, the initial strain corresponds to a load duration of 0.01 day (approximately 15 min) (Carreira and Burg 2000).

Although often done by researchers, the committee recommends that the strain should not be separated into initial and creep strains, due to the loading rate factors that affect the estimated initial strain at loading.

1.2.10 *Creep strain*—Creep strain represents the time-dependent increase in strain under sustained constant load taking place after the initial strain at loading. It is obtained from the load-induced strain by subtracting the initial strain defined in Section 1.2.9. The creep strain may be several times greater than the initial strain. Creep strain may be subdivided into a drying and a nondrying component, termed drying and basic creep, respectively.

1.2.11 *Basic creep*—Basic creep is the time-dependent increase in strain under sustained constant load of a concrete specimen in which moisture losses or gains are prevented (sealed specimen). It represents the creep at constant moisture content with no moisture movement through the material, and is consequently independent of the specimen size and shape.

To determine basic creep, it is necessary to measure the deformations of a set of sealed specimens under constant load and to determine the total strain; and, if autogenous shrinkage cannot be neglected, deformations of companion sealed, load-free specimens should be measured. It has not been determined whether basic creep approaches a final value, even after 30 years of measurement of sealed specimens (Bazant 1975; CEB 1993).

1.2.12 *Drying creep*—Drying creep is the additional creep occurring in a specimen exposed to the environment and allowed to dry. As it is caused by the drying process, drying creep depends on the size and shape of the specimen and may be expected to show a limiting value at long term (RILEM TC 107 1995; Al-Manaseer, Espion, and Ulm 1999; Bazant 1999; Bazant and Baweja 2000).

Three sets of specimens are required to determine the drying creep: a loaded set that is allowed to dry to determine the total strain, a loaded set of sealed specimens to determine basic creep, and a load-free set at drying to determine the total shrinkage strain (Carreira and Burg 2000). This is mathematically described in Eq. (1-1).