Construction and Building Materials 121 (2016) 622–628

Contents lists available at ScienceDirect

Construction and Building Materials

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

Pulse velocity assessment of early age creep of concrete

R. Latif Al-Mufti *, A.N. Fried

Civil, Chemical and Environmental Engineering, Faculty of Engineering and Physical Sciences, University of Surrey, Guildford GU2 7XH, UK

HIGHLIGHTS

- Creep is affected by the aggregate type and porosity.
- The bond between aggregate and cement paste significantly affects early age creep.
- Ultrasonic pulse velocity can provide indication of creep deformation for concrete.
- We have established empirical models between specific creep and UPV of concrete.
- Creep-UPV models have power form for the alternative aggregate concretes (w/c 0.5).

ARTICLE INFO

Article history:
Received 25 November 2014
Received in revised form 3 June 2016
Accepted 8 June 2016
Available online 18 June 2016

Keywords:
Concrete
Creep
Strength
Aggregate
Cement
Velocity

ABSTRACT

Creep of concrete can have damaging effects by inducing deformations that may contribute or eventually lead to cracks, which influence concrete durability, steel reinforcement exposure to corrosion, and aesthetic damage to architectural buildings. This research investigated the early age creep deformation in concrete samples made with normal, lightweight (Lytag), recycled concrete, and recycled asphalt aggregates using ultrasonic pulse velocity measurements. Creep was achieved by applying a load corresponding to 30% of the strength of concrete to 100 × 250 mm prisms. The compressive load was applied from 24 h after mixing and up to 27 days. The results and analysis of measurements obtained for stress development, specific creep (creep strain per unit stress), and ultrasonic pulse velocity measured up to 27 days after load application are presented. Empirical models that allow the assessment of creep of concrete using ultrasonic pulse velocity measurements are also presented.

Early age specific creep is higher for recycled asphalt aggregate than Lytag aggregate and recycled concrete aggregate concretes, which are higher than gravel concrete. Measurements of ultrasonic pulse velocity could be used to determine creep but further work to refine this technique is required.

1. Introduction

Creep is the deformation of concrete with time, when it is under a sustained load. It continues at a decreasing rate as the stress is maintained. It follows an instantaneous elastic strain and a "near" instantaneous inelastic initial creep strain which takes from 10 to 100 min to develop [1–3]. The creep behaviour of concrete, resulting from sustained load application, became apparent at the beginning of the 20th century [4].

Creep can have damaging effects by inducing cracks in concrete which affects concrete durability allowing reinforcement to corrode and are undesirable aesthetically. It can also cause loss of stress in pre-stressed concrete, increase in deflection over time of large span concrete beams, and cladding buckling problems in tall buildings [1].

Creep does not always have harmful effects, although it may seem that it does. One of its benefits in structures is enabling concrete to undergo strain deformations so relieving concrete stresses and avoiding what could otherwise be a ductile type collapse of concrete columns and beams. Further, creep in the elastic range at an early age may have the potential for inhibiting subsequent pre-stress loss in post-stressed concrete beams [5].

Concrete can also experience strain deformations that are time dependant, without the application of load, in the form of shrinkage [1–3,6,7].

Creep of concrete is affected by many factors that either relate to internal concrete composition or to external effects of the environment and size of the concrete member. Some of the main factors include; water/cement ratio, curing conditions, temperature and relative humidity, size of concrete member, aggregate type

* Corresponding author at: CCE-FEPS, University of Surrey, Guildford GU2 7XH, UK.

E-mail address: ral-mufti@engineer.com (R.L. Al-Mufti).

http://dx.doi.org/10.1016/j.conbuildmat.2016.06.015
0950-0618/

and volume, bonding, cement type, degree of compaction, and admixtures [1,2,4,6–8]. To examine in depth all the variables affecting creep was beyond the scope of this research and whilst these influences are acknowledged the aim of this project was to establish a method of assessing early age creep of concrete using ultrasonic pulse velocity, and to obtain a relationship between early age creep and ultrasonic pulse velocity for four different concrete types.

2. The mechanism of creep

Creeping concrete can be regarded as a multi-phase material consisting of cement paste and aggregate. The aggregates, which can occupy up to 75% of a concrete's volume, are bonded together by the cement paste and act as a restraining material [1].

The cement paste consists of unhydrated cement grains surrounded by cement gel and water-filled or empty capillary pores [2,6]. The cement gel consists of intertwined particles of mainly crumpled colloidal sheets of calcium silicate hydrates, some are needle-shaped, with a continuous system of water-filled gel pores. Creep is thought to occur when the colloidal sheets slide through a de-bonding and re-bonding process when under stress. The unstable contact between the sheets becomes weaker when water is present; hence creep is reduced after drying [2,6,8].

Drying of concrete under load causes water to diffuse out of the stressed gel micropores meaning the colloidal structure moves closer together, which results in additional shrinkage, known as drying Shrinkage [2,6,7]. According to Bazant and Wittmann [6], and Bazant and Chern [8], this could be enhanced by compressive stresses and existing microcracking, induced by earlier drying and result in further shrinkage. Creep that occurs under controlled conditions of no moisture movement to or from the environment is termed basic creep.

3. Calculation of concrete creep

The total strain generated by concrete under applied compressive stress includes initial elastic strain, strains related to the effects of environmental conditions, such as shrinkage strains, and in addition creep strains [7]. Therefore, in controlled environmental conditions, such as a laboratory, the actual creep strain from loading is obtained by subtracting from the total strain the elastic strain and the environmental strains obtained from an unstressed control specimen stored in the same environmental conditions as the stressed concrete. This is expressed by Eq. (1).

$$\varepsilon_{creep} = \varepsilon_{total} - \varepsilon_{initial} - \varepsilon_{control}\ (\mathrm{mm/mm}) \quad (1)$$

where

ε_{creep} = creep strain.

ε_{total} = total strain in stressed concrete.

$\varepsilon_{initial}$ = initial strain, measured immediately after applying the load.

$\varepsilon_{control}$ = strain obtained from control concrete, which includes shrinkage.

4. Materials and experimental method

4.1. Materials

4.1.1. Cement type

The cement used in all the mixes of concrete investigated was CEM I Portland Cement (PC) type 42.5 N, manufactured by Lafarge Blue Circle. This was a general purpose cement of a quality that complies with BS EN 197-1:2011 [9] and carries the European conformity CE marking.

4.1.2. Mixing water

Ordinary fresh tap water was used throughout, as supplied by Thames Water Utilities Limited. This water is considered as suitable for use in concrete in accordance with BS EN 1008:2002 [10]. The water was used at ambient temperature.

4.1.3. Aggregates - fine and coarse

All the different types of aggregate (normal, RCA, recycled asphalt, and lightweight) used in the manufacture of concrete were oven dried and allowed to cool before use. Concrete mixing water was adjusted for the absorption of different aggregates. The aggregates were allowed to absorb water for 24 h prior to mixing.

4.1.3.1. Normal (gravel) concrete. For gravel concrete, Thames Valley flint gravels (4/10 mm and 10/20 mm) and uncrushed river sand (0–4 mm all-in) were used throughout the experimental work. The fine aggregate particle sizes were found to have the grading proportions shown for sand in Table 1. The water absorption and relative density of the aggregates were measured based on a saturated surface dry basis as outlined by BS EN 1097-6:2000 [11], and also shown in Table 1.

4.1.3.2. Recycled concrete aggregate (RCA) concrete. The aggregate used in RCA concrete consisted of sand (0–4 mm all-in) for fine aggregate, as used in normal concrete, and RCA aggregate (5–20 mm all-in) for coarse aggregate. The RCA was Class RCA (II), in accordance with Recycled Aggregates BRE Digest 433 [12], supplied by Day Group Ltd, Middlesex, UK. The grading and constituent material proportions of RCA are listed in Table 2. The relative density (saturated surface dry) and water absorption of RCA are also listed in Table 2.

4.1.3.3. Recycled asphalt aggregate (RA) concrete. Asphalt is a mixture of aggregates, such as gravel, and bituminous binder. Recycled asphalt is reclaimed asphalt obtained by the milling of asphalt road layers.

Table 1
Sand gradation with relative density and water absorption for sand and gravel.

Sieve size (mm)	% passing
Sand grading	
2.36	94.3
1.18	84.2
0.6	73.7
0.3	49.9
0.15	9.38
Sand	
Relative density (SSD)	2.2
Water absorption	2.91%
10 mm gravel	
Relative density (SSD)	2.48
Water absorption	2.71%
20 mm gravel	
Relative density (SSD)	2.48
Water absorption	2.18%

Table 2
RCA size and constituent gradation with relative density and water absorption.

Sieve size (mm)	% passing
31.5	100
20	97.3
10	37.1
9.5	33.6
5	2.4
2.36	0.5
RCA constituent materials	% of total
RCA	96.6
Yellow brick	0.7
Red brick	0.6
Asphalt	2.0
Glass	0.03
Other	0.1
Relative density (SSD)	2.04
Water absorption	5.35%