Modelling of Basic Creep of Concrete

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***Abstract*- Creep of concrete is a time dependent phenomena which affect the safety and serviceability of the concrete structural elements. While there are number of models such as ACI 209R-92, CEB, GL2000, B3 and B4, which has been developed to predict creep of concrete, these models need further improvement especially in the prediction of basic creep. Investigations by various researchers have shown that the creep of concrete originates from the creep of Calcium Silicate Hydrate (CSH), the basic building block of cement concrete. The main objective of this paper is to relate the basic creep compliance with the CSH content in concrete. Experimental basic creep compliance values are taken from literature. Since these values cannot be directly related with CSH content of cement paste, using a multiscale approach, the basic creep compliance at concrete scale is scaled down to cement paste scale. The amount of CSH content present in the cement paste at different times is determined using the cement hydration model proposed in literature. From the results obtained, it is noted that the basic creep compliance of cement paste is related to the change in CSH content after loading.**

1. INTRODUCTION

Concrete is complex matrix which consists of cement as a binder and aggregates as filler. In concrete structures, the prediction of long term deformations due to creep and shrinkage is a difficult process. The experiments used to predict these types of deformations are very costly and take several years. These deformations need to be considered in the design stage itself. Deformations due to creep and shrinkage affect the structural stability, durability, and serviceability.

Number of empirical and phenomenological model has been proposed by various researchers for predicting creep and shrinkage of concrete. Details of most commonly used models to predict creep and shrinkage of concrete are presented in ACI 209R [15]. The performance/calibration of these models has been studied using the experimental data, and many of these models are incorporated in codes of practice. However, the recent failures of bridges [11] indicate that there is a need to have a better understanding of the phenomenon of creep and/or to develop refined models.

1.1 *Origin of Creep*

Creep of concrete, which originates from the Calcium Silicate Hydrate (CSH) in the hardened Portland cement paste. CSH constitutes up to 60% of the hydration products in hardened cement paste and it is mainly responsible for some of its principal properties such as strength, creep, shrinkage and durability. A significant amount of hydration products are formed within the first few days after mixing for a typical w/c of 0.3-0.6. The precipitation rate of CSH on the surface of the anhydrous calcium silicates decreases as the rate of reaction involved in the hydration process decrease. Ulm and co-workers [7], based on nanoindentation tests on cement paste, identified that the creep of concrete is due to the rearrangement of the nanoscale CSH particles.

The objective of the present study to examine the relation between CSH content and basic creep compliance of cement paste, using experimental results available in literature. The CSH content in cement paste is determined using a hydration model proposed in literature. The experimental results on basic creep of concrete are downscaled to cement paste level using a multiscale approach. The details of the studies are presented in the following sections.

2 MODELLING OF CSH CONTENT IN CONCRETE

2.1 Hydration model

The kinetic process of hydration of Portland cement [1] consists of three processes: an initial dormant period, a phase boundary reaction process, and a diffusion controlled process. In this model the degree of hydration is expressed for both cement hydration and FH reactions. This present study considering only hydration of cement and it is expressed in Eqn (1); in this model considering three coefficients: k_d, the reaction coefficient in the induction period: D_e, the effective diffusion coefficient of water through CSH gel: k_r, reaction rate constant; in which the terms k_d and D_e are function of degree of hydration, as shown in Eqn (2,3).

$$\frac{d\alpha}{dt}=\frac{3\left(\frac{S_w}{S_o}\right)*\rho_w*C_{w\text{-free}}}{(\upsilon+w_g)*r_o*\rho_c)}\frac{1}{\left(\frac{1}{k_d}-\frac{r_o}{D_e}\right)+\frac{r_o}{D_e}(1-\alpha)^{-\frac{1}{3}}+\frac{1}{k_r}(1-\alpha)^{-\frac{2}{3}}} \quad (1)$$

$$k_d=\frac{B_{cc}}{\alpha^{1.5}}+C_{cc}*\alpha^3 \quad (2)$$

$$D_e=D_{e0}*\ln\left(\frac{1}{\alpha}\right) \quad (3)$$

The weight fractions and coefficients of the reactions are taken from Papadakis [3]. The chemical reactions of mineral compounds of Portland cement [10] can be expressed as,

$$2C_3S+6H \rightarrow C_3S_2H_3+3CH$$

$$2C_2S+4H \rightarrow C_3S_2H_3+CH$$

The mass of calcium hydroxide (mCH) and calcium silicate hydrates (mCSH) produces in the hydration process is calculated from Eqn (4,5). :

$$mCH(t) = C_o*RCH_{CE}*\alpha+1.321*CF(t)-\upsilon_{FH}*\alpha_{FH}*P \quad (4)$$

$$mCSH(t) = 2.85\ (f_{S,c}*\alpha*C_o+\gamma_S*f_{S,c}*\alpha_{FH}*P) \quad (5)$$

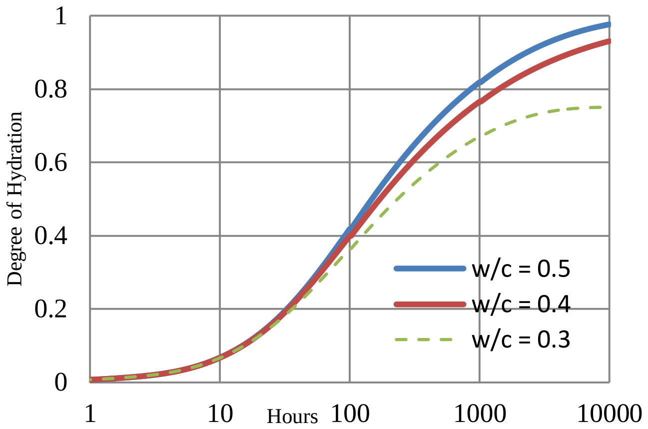


Fig. 1 Degree of hydration with different w/c ratios

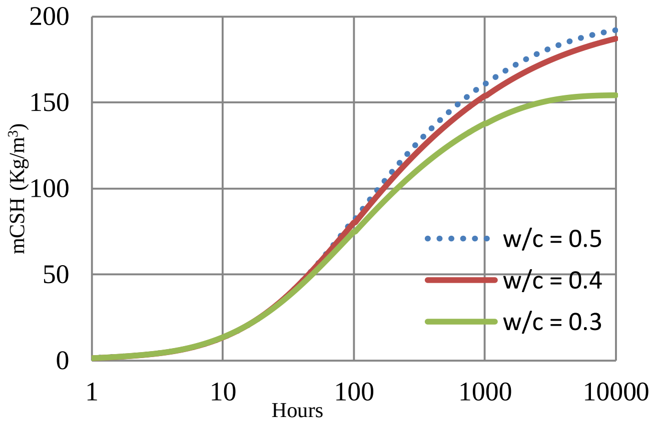


Fig. 2 CSH content with different w/c ratios

The evaluation of results from the model, degree of hydration and mass of CSH content for ASTM Type I cement with different water cement ratios (0.3, 0.4, 0.5) are shown in Fig. (1,2). From Fig (1,2), it is noted that at any given time, degree of hydration and CSH content are higher for higher values of w/c.

3. MODELLING BASIC CREEP OF CONCRETE

The basic creep compliance data for different concrete mixtures loaded at different ages are collected from literature. This basic creep of concrete is downscaled to basic creep of cement paste using the multiscale approach proposed by Pichler and Lackner [5].

3.1 Downscaling of creep compliance

If $J_{concrete}$ is the concrete creep compliance, than the creep compliance at the mortar level (J_{mortar}) and cement paste level (J_{paste}) are obtained as [5].

$$J_{mortar} = \frac{J_{concrete}}{f_m / f_m + \frac{5}{2}(1\text{-}f_m)} \quad (6)$$

$$J_{paste} = \frac{J_{mortar}}{f_m / f_m + \frac{5}{2}(1\text{-}f_m)} \quad (7)$$

3.2 Relation of basic creep compliance with CSH content

The basic creep compliance of cement paste is related to the CSH content after loading using an exponential relation of the form:

$$J_{paste}=a*\exp(b*(mCSH(t\text{-}t_0)) \quad (8)$$

4. RESULTS AND DISCUSSION

In this study, the basic creep compliance values are taken from experimental investigations reported by Le Roy [12], Ohnuma [13], and Min [14]. The concrete mix proportions and the age at loading (t_0) for these experimental investigations are given in Table 1.

Table 1 Inputs and Correlation Coefficients from the model

Authors	**Mix Details**	**t_o (Days)**	**mCSH (t-t_o) Ratio**		
			a	**b**	**R**
Le Roy	C = 342 kg/m³ w/c = 0.5 a/c = 5.46 f_{c28} = 43.5 MPa	3	867.8	0.004	0.984
		7	781.9	0.006	0.985
		28	739.2	0.011	0.977
Ohnuma	C = 299 kg/m³ w/c = 0.629 a/c = 5.753 f_{c28} = 24.6 MPa	3	2064	0.005	0.987
		7	1801	0.008	0.983
		28	1407	0.019	0.971
Min	C = 473 kg/m³ w/c = 0.328 a/c = 3.75 f_{c28} = 48.7 MPa	3	1285	0.006	0.994
		7	991.9	0.011	0.999
		28	1095	0.012	0.986

Using the hydration model presented in Section 2, the variation in CSH content with time for these concrete mixtures are determined. Using Eqn (6,7), the concrete creep compliances are downscaled to cement paste level. The variation of basic creep compliance of cement paste with CSH content after loading are shown in Fig (4(a)-4(c)).

Equations of the form of Eqn (8) are fitted between the CSH content and basic creep compliance of cement paste for all the three concrete mixtures considered. The values of coefficients 'a' and 'b' in Eqn (8) are obtained and are given in Table 1, along with the correlation coefficient (R). It is noted that for all the cases considered, the value of R is very high, suggesting that the predicted basic creep compliance values using the proposed model are in good agreement with those observed from experimental investigations. Therefore the proposed model can be used for predicting the basic creep compliance of cement paste. However, there is a need to determine the coefficients of the model using the mix details. After predicting the basic creep compliance of cement paste, the basic creep of concrete can be determined by using the upscaling procedure given by Pichler and Lackner [5].

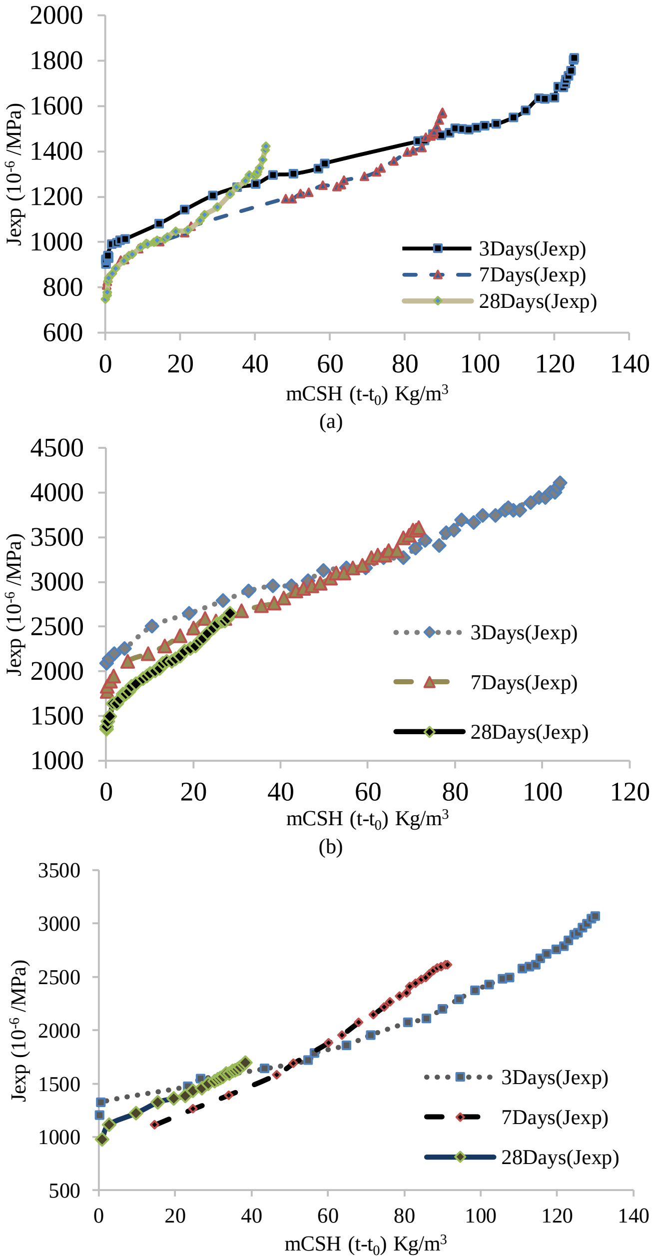


Fig. 3 Variation of creep compliance with CSH content at different ages of loading. (a) Le Roy; (b) Ohnuma; (c) Min

4.1 Upscaling procedure

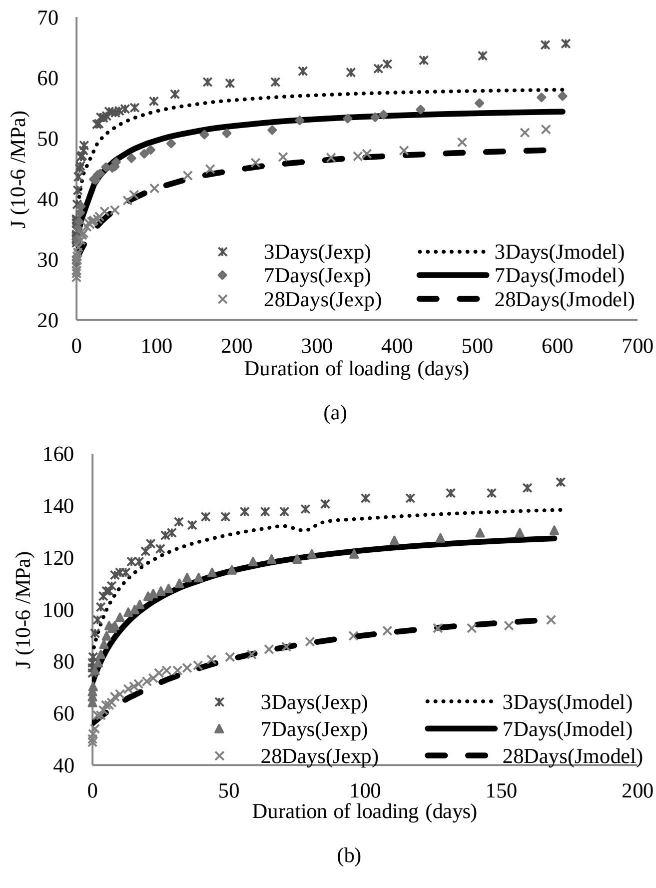
Upscaling process is carried out by using the continuum micromechanics [5], considering a simple microstructure and volume fractions of the constituents corresponding to the complete degree of hydration. Upscaling towards micro (cement paste) scale to macro (concrete) scale is given by:

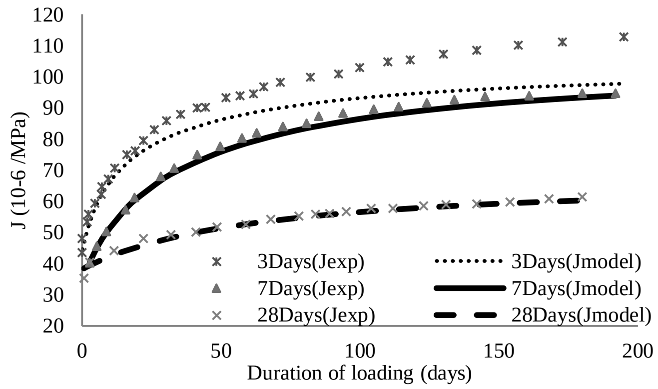
$$J_{mortar} = J_{paste} * \frac{f_m}{f_m + \frac{5}{2}(1-f_m)} \quad (9)$$

$$J_{concrete} = J_{mortar} * \frac{f_m}{f_m + \frac{5}{2}(1-f_m)} \quad (10)$$

Where f_m is the volume fractions of fine and coarse aggregates. The creep compliance (J_{paste}) of micro scale is used as input of upcoming scales.

For the three concrete mixtures considered, the J values obtained from the proposed approach with those reported from the experimental investigations are given in Fig. (5(a)-5(c)). From these figures, it is noted that the proposed approach is able to predict the concrete creep compliance satisfactorily.





(c)

Fig. 4 Comparison of model response with experimental results: (a) Le Roy; (b) Ohnuma; (c) Min.

5. SUMMARY

An approach for predicting the basic creep compliance of concrete ($J_{concrete}$) is proposed in this paper. This approach is based on the assumption that the creep of cement is originated from CSH content. The CSH content is predicted using the hydration model proposed by Wang [1]. The comparison with experimental results available in literature shows the efficacy of the proposed approach. There is a need to generalize the proposed approach by also incorporating the concrete mix details in the relation between CSH content and creep compliance of concrete.

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