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Analytical Investigations On Early-Age Strains In Concrete

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Abstract: *Early-age shrinkage of concrete is an important issue, leading to formation of cracks in the concrete structures which affects its stability, durability and serviceability. The major factor causing early-age strains in concrete is the chemical shrinkage. In this paper, a study on influence of cement content and water-cement ratio on the chemical shrinkage is studied. A mathematical model is used for the prediction of chemical shrinkage at early ages. The hydration kinetics model for clinker phases proposed by Parrot and Killoh is implemented in the model of concrete at early-ages. From the results, it is observed that chemical shrinkage increases with increase in cement content and water/cement ratio.*

Keywords: *Early-age shrinkage, chemical shrinkage, hydration, cement content, water-cement ratio.*

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I. INTRODUCTION

Concrete is a material extensively used in the construction industry, consisting of cement as hard matrix used to fill the space between aggregate particles; aggregate will act as filler which is embedded in the matrix. Concrete shrinkage is an important consideration when focusing on durable structures. Shrinkage in concrete is due to movement or loss of water. As the water is lost either evaporation (drying shrinkage) or internal chemical reactions (autogenous shrinkage) tensile stress are generated. These stress pull the cement paste close together which registers as volume reduction.[1] Shrinkage will be taken place in two phases, early age and later age. Early age shrinkage of cementitious material is a result of several physico-chemical phenomena. Those are related to hydration reaction of cement and water and to the progressive hardening of mineral skeleton.[2] These early age volume changes are typically ignored in concrete structures because magnitude of this shrinkage is much less than shrinkage resulting from drying , but when curing conditions are ideal these early age shrinkage will lead to cracking risk.[1]

In concrete structures the prediction of early age deformation is a difficult process. The experiments used to predict these types of deformations are very costly and it will take several years. In the designing process itself we need to consider these factors to produce safely designed structures. Especially creep and shrinkage are major phenomena which affects the structural stability, durability, and serviceability. . In this paper, modeling of early-age hydration of cement proposed by Parrot and Killoh is used in which the effects of chemical composition and fineness of cement as well as water-cement ratio are taken into account. Based on degree of hydration, volume of chemical shrinkage is calculated mathematically by using molecular weights of cement compounds.

II. EARLY-AGE SHRINKAGE

Early-age is defined as the first day, while the concrete is setting and starting to harden. Early-age shrinkage is defined as the volume changes occurring immediately after concrete placing up to the age of 24 hours. Early-age shrinkage is great concern because it is during early hours, immediately after casting, that concrete has the lowest tensile strain capacity and is most sensitive to internal stresses. Early-age shrinkage and cracking in cement based material is due to the development of modern concretes which are more sensitive to cracking immediately after setting, as well as advent of new additives such as shrinkage reducing admixtures and fibres which induce early-age cracking in conventional and high performance concretes. This early-age cracking sensitivity in modern concretes is to a large extent the result of low w/c ratio and higher cement content typical of higher cement performance of concrete (HSC/HPC). Lower w/c will increase autogenous shrinkage and high cement content increases ultimate drying shrinkage of HSC/HPC and other concrete materials.In early age autogenous shrinkage is due to chemical shrinkage and later age due to self-desiccation. Early-age shrinkage can result in cracks that form in the same manner in later-ages. It is suggested by VTT and others that if the early age shrinkage exceeds 1mm/m there is a high risk of cracking. Still there is a problem in measuring early-age shrinkage, there is no standardized method to measure early-age length change as there is for long term shrinkage (ASTM C157). ASTM 827 is the only standardized test to measure early-age shrinkage of concrete. This test method is limited as vertical movement can be measured. The most common instrument for measuring strain is vibrating wire strain gauge.

The most common solution to reduce early age volume changes is to avoid drying by proper handling of the concrete for the first few hours after placement.

III. CHEMICAL SHRINKAGE

Chemical shrinkage is a result of the reactions resulting between cement and water, which lead to volume reduction. The primary suspect for early age autogenous shrinkage was chemical shrinkage, which is an internal volume reduction while the autogenous shrinkage is an external volume change.To predict the chemical shrinkage accurately it is necessary to know which reaction phase is occurring at that specific point in the hydration procedures.

A total chemical shrinkage during the hydration of cement is caused by the smaller volume of products (e.g calcium silicate hydrate gel and calcium hydroxide) compared with the reactants (e.g alite and water). As a rule of thumb, the total chemical shrinkage at 100% hydration is about 6.25 ml/100g cement (i.e 25% of the chemical bound water to cement ratio of 0.25)

The total chemical shrinkage is sum of external chemical shrinkage and the volume of empty pores at all stages. In literature there is a confusion total chemical shrinkage may be named as chemical shrinkage, water absorption, volume contraction or Le chatelier shrinkage. External chemical shrinkage is also named as external volume change, bulk shrinkage and autogenous shrinkage

The methods of measuring total chemical shrinkage all have in common that the sample has to be kept water saturated and that the water needed to replace the volume decrease is measured, while the common methods for measurements of external chemical shrinkage are characterized by sealed curing of the cement paste. There are mainly three techniques for measuring chemical shrinkage.1) dilatometry 2) gravimetry 3) pyconometry

.The basic reactions of cement clinker are well understood and generally defined by four reactions of C3S,C2S,C3A and C4AF. Each of these reactions requires water for reaction, are exothermic and result in a decreased volume of reaction products.

C3S :2 C3S + 6H → C3S2H3 + 3 CH
C2S:2 C2S + 4H → C3S2H3 + CH
C3A:C3A + 6H → C3AH6
C4AF: C4AF + 2CH+10H → C3AH6 + C3FH

3.1Computationof chemical shrinkage

This volume reduction, or chemical shrinkage, begins immediately after mixing of water and cement and the rate is greatest during the first few hours .The magnitude of chemical shrinkage can be estimated using the molecular weights and densities of the compounds as they change from the basic to reaction products.(see table 1)

Table 1:Reaction of C_3 S during cement hydration

B A S I C		**mol.wt.(g/mol)**	**density(g/cm^3)**	**mol.vol(cm/mol)**	
	$2C_3S$	456.630	3.130	145.884	$=v_B$
	6H	108.089	0.998	108.284	
	Basic Total	564.719		254.172	
P R 0 D U C T S	$C_3 S_2 H_3$	342.449	2.630	130.207	
	3CH	222.275	2.230	99.675	$=V_c$
	Reaction Total	564.716		229.882	
			difference	24.290	$=V_s$

The difference in the molecular volume of the basic (Vb) and reaction (Vr) products give the volume of shrinkage, Vs. Then it is necessary to relate the shrinkage volume to the original solid mass of the basic product

Vcs =V_S/M = 24.290/456.630 = 0.0532 cm3/gm , for C3S

All four of the individual phases can be calculated in the same manner. Then each factor is used in a full equation to predict chemical shrinkage of cement. Table 2 gives the 4 chemical shrinkage values for each cement phase.(see table 2)

Table 2: Chemical shrinkage values for individual cement phases.

Chemical Compositions	**Chemical Shrinkage (cm^3/g)**
C_3S	**0.0532**
C_2S	**0.0400**
C_3A	**0.1785**
C_4AF	**0.1113**

A generalized way to estimate the chemical shrinkage is given by,
VCS-TOTAL=0.0532[C3S]+0.0400[C2S]+0.1785 [C3A]+0.1785 [C4AF]
Where[x] is the mass of [x] given, (x= C3S,C2S,C3A,C4AF).
The rate of chemical shrinkage is depends on water/cement ratio and cement content. Higher magnitude of chemical shrinkage due to quicker cement reactions during early hours will lead to autogenous shrinkage.

IV. HYDRATION MODEL

In the structural modeling of concrete maturing, the concept of hydration degree is often used [8,10]. In this work, The thermodynamic hydration model is used to calculate the degree of hydration of cement .Initially the rates of hydration of each clinker phases are determined and it is used as a time dependent input to calculate the degree of hydration of individual clinker phases. The mass fraction of clinker phases, volume of water, molar masses of clinker phases and hydrated products of cements are used as a input to predict the overall degree of hydration of cement[8]. According to the hydration model,

The final rate of hydration degree for a single clinker constituent is calculated as
6

The degree of hydration at time t (in days) is then expressed as
(7)

(Nucleation and growth) (8)
(Diffusion) (9)
(Shell formation) (10)
In this paper, the empirical expressions (Equ (6),(8),(9),(10)) as given by Parrot and Killoh [9] are used together with their values of K_1,N_1,K_2,K_3,N_3 as compiled in Table4. The influence of w/c according to =(1+4.444*(w/c)-3.333*)^4 for [26] as well as the influence of the surface area on the initial hydration is included using the data given in Parrot and killoh [9]

Table 3: Parameters from Parrot and Killoh [9] for the hydration model

parameter	**clinkers**			
	Alite	**Belite**	**Aluminate**	**Ferrite**
K1	1.5	0.5	1	0.37
N1	0.7	1	0.85	0.7
K2	0.05	0.006	0.04	0.015
K3	1.1	0.2	1	0.4
N3	3.3	5.0	3.2	3.7

All parameters from Ref. [9] for OPC

Dependent upon the purpose of modeling, this can be the overall degree of hydration αhydr of cement, where hydration is treated as the sum of reactions, or the degree of hydration of single cement constituent modeled separately for each constituent. By definition, these quantities can be bound by means of weighted averaging.

αhydr= fC3S α C3S + fC2S α C2S + fC3A α C3A + fC4AS α C4AS (11)

where fx is the relative mass fraction of individual cement compound x (c3s,c2s,c3a,c4af) determined based on e.g. Bogue's compound or quantitative analysis, αx is the degree of hydration of individual. compound x. In Fig.1 evolution of hydration degree for different water/cement ratio (0.45,0.5,0.55) with time is presented. It shows that , degree of hydration is depends on water-cement ratio, with increases the water-cement ratio the degree of hydration value is increased with time

Table 4 : input parameters for hydration model

Compounds	C_3S	C_2S	C_3A	C_4AF
CP1 +M1	**0.543**	**0.187**	**0.076**	**0.073**

Fig 1:over all degree of hydration for differentw/c

V. PARAMETRIC STUDIES

The effects of changes in water-cement ratio and cement content on chemical shrinkage of a concrete cylinder (150 mm *300 mm) is studied.

5.1 Effect of water/cement ratio

Chemical shrinkage is important property of low water-cement(w/c) ratio of cementitious systems, since it is considered the main cause of autogenous shrinkage. it is commonly assumed that chemical shrinkage is directly proportional to the degree of hydration and is independent of water/cement(w/c) ratio. Accordingly, reducing the w/c ratio will reduce the slump value which leads to a considerable decrease in the shrinkage strains and the porosity of the cement paste.

In this study, Investigation on variation of water/cement ratio that changes the chemical shrinkage magnitude during early days is considered. The chemical shrinkage of cylinder at 28 days for different w/c ratio (0.45,0.5,0.55) and different cement content (300 kg/cm3,320kg/cm3,340kg/cm3,360kg/cm3) is presented. Finally, the chemical shrinkage value increases with increase in water/cement ratio.

Fig 2 : Effect of cement content on chemical shrinkage a) w/c= 0.45 ; b) w/c = 0.5 ; c) w/c = 0.55

5.2 Effect of cement content

Another factor related to Chemical shrinkage is cement content. The cement content determines the fraction of cement paste in concrete as shrinkage increases with respect to cement paste content, hence represents the shrinking phase of the material. In this present study, chemical shrinkage of cylinder at 28 days with varying cement content is presented. The result obtained shows that with the increase in the cement content , the chemical shrinkage value is increased.

Fig 3 : Effects of water-cement ratio on chemical shrinkage a) cement content = 300 kg/cm3 b) cement content = 320 kg/cm3 c) 340 kg/cm3d) 360 kg/cm3.

VI. SUMMARY

Chemical shrinkage is a major phenomena which affects the durability and serviceability of concrete structures. We can observed a considerable variations in chemical shrinkage for different values of cement content and water-cement ratio. Therefore an attempt is made to study the change in chemical shrinkage with variation of cement and water –cement ratio. Hence after a detailed study it is to be observed that chemical shrinkage increases with increase in cement content and water-cement ratio.

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