CREEP AND SHRINKAGE OF ECOLOGICAL SELF CONSOLIDATING CONCRETE

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Abstract:

Optimizing concrete mixtures with regard to replace a part of cement content with supplementary cementitious materials can prompt the design of ecological-self consolidating concrete. By replacing more than 60% of cement with residual product from other industries such as Fly Ash, Micro Silica, and lime, the energy consumption and CO2 emission of concrete are reduced. This study was performed to monitor the creep and shrinkage of high volume supplementary cementitious material of self consolidating concrete (HVSCM-SCC) and ensure desired performance of concrete. Total sixteen and Twenty Four specimens from different concrete mixtures with different replacement level (up to 75% of cement replacement) were monitored for creep and shrinkage respectively. Moist and accelerated curing regimes were utilized in this study to see the effect of accelerated curing on creep and shrinkage of HVSCM-SCC. Mechanical properties of different age 1,3,7,28,56 and 90 days were conducted. Experiments have shown that 75% level replacement of cement experienced low creep and shrinkage rate than other mixtures. The creep and shrinkage values of HVSCM-SCC were compared to prediction models proposal by AASHTO LRFD (2007), ACI-209R (2009), and AS 3600 (2009) to ensure the validity of these models for HVSCM-SCC.

KEYWORDS

Ecological, HVSCM-SCC, Accelerated curing, Creep, Shrinkage.

INTRODUCTION

Climate change is an issue and starts to concerning the world's environmental. Concrete is by far the most widely consumed resource in the world with water being the only resource to exceed it. In general, concrete is a mixture consists primarily from cement, sand, coarse aggregate, and water. The principal cementitious material in concrete is Portland cement .However, about 50% of the total CO2 emitted in construction of concrete structures comes from use of Portland cement. By reducing the cement content, CO2 emissions of concrete and energy consumption are reduced (Fennis *et al*. 2011). Also, with development of construction in last decades, the principle materials during processing cement have been increased. It should be taken into account that the natural resource employ in concrete are finite. Therefore, the civil engineers would have to consider the three aspects (reduce, reuse, and recycle) in all aspects of any construction of concrete structural. In other words, the sustainable of construction needs to be taken into account. To improve the environment friendliness of concrete, Ecological concrete has become a reasonable solution to prompt this aspect of concrete. Ecological concrete could properly define as any concrete using waste materials in place of Portland cement or aggregate. These waste materials are by products from other processes material. Fly ash, slag, and silica fume are some of byproducts materials that use as supplementary cementitious materials to replace a portion of Portland cement and satisfy the aspect of sustainability. Furthermore, using the SCMs is considering economic and ecological disposal of millions of tons of industrial by-product that can be safely incorporated as cementitious materials in concrete.

SCC is an innovation concrete material used successfully throughout the world. It can be consolidated into every corner of a framework, purely by means of its own weight and without the need for mechanical consolidation (Daczko 2012). One of the solutions to satisfy flowability of SCC is by using sufficient amount of paste (Higher cement content) and to control the heat generation, portion of cement can be replaced with SCMs. Traditionally, up to 25% of the cement can be replaced with SCMs. Exceeding this level is considered to be high volume SCM and appropriate testing should be conducted to ensure desired performance of concrete.

Creep and shrinkage are two important time-dependent properties of concrete. They are one of critical factors for design of structural members due to the length change over time (Brewe *et al*. 2010). Using high volume of supplementary cementitious material in self consolidating concrete could raise questions regarding the performance of this type of concrete. Differences in the amount of time dependent losses in this type of concrete are one of these questions. To answer some of these concerning, this study was conducted to understand the creep and shrinkage behavior of HVSCM-SCC. An experimental study has been conducted to determine the amount of creep and shrinkage strain. The measuring data has been compared with predictive equations from ACI 209R-09, AASHTO LRFD 2007, and AS3600 to determine whether these typical Equations used by design engineers can be applied to HVSCM-SCC under condition of construction local materials and different curing conditions.

EXPERIMENTAL WORK

Materials

Portland cement type I that conforms to the ASTM C-150 was used. A high calcium type C fly ash that meets the ASTM C-618 was used as a binder to produce concrete. Moreover, micro silica fume and hydrated lime type S were used in this investigation. The specific gravities of cement, fly ash, micro silica fume, and hydrated lime used were 3.15, 2.68, 2.3, and 2.5 respectively. Natural sand with 0.25 in (6.35 mm) maximum size was used as fine aggregate and 2.56 specific gravity. The coarse aggregate used in this study was 0.5 in (12.5 mm) maximum size a crushed stone dolomite and it had a 2.77 specific gravity. A commercially available HRWRA was also used to maintain the workability of self-consolidating concrete.

Mix Proportions

The focus of this study was to explore the effects of replacing various percentages of Portland cement with SCMs to develop a sustainable concrete with long term performance. The control mix used in this study was designed to have 10000 psi (69.8 MPa) of compressive strength at 28days. The water to binder ratio (w/b) and aggregate and cement content was held constant for all mixtures. A cementitious content of 850 pcy (504 kg/m3) was used. Depending on optimum packing density, the fine to total aggregate ratio was determined to be 0.52. Intensive Compaction Tester machine (ICT) was utilized to obtain the optimum packing density of aggregate that satisfy the self-consolidating requirements. Table 1. illustrates all mixtures of this study.

Table 1 Mixture proportions

Mixture compositions (lb/yd^3)*

Composition	Type	Unit	Mixtures			
			M1	M2	M3	M4
Cement	Type I	lb/yd^3	850.0	340	212.5	212.5
Fly Ash	Type C	lb/yd^3	0.0	425	510	510
Silica Fume	Elkem Micro silica	lb/yd^3	0.0	85	85	42.5
Hydrated Lime	Type S	lb/yd^3	0.0	0.0	42.5	85
Sand	River Sand	lb/yd^3	1475.0	1475	1475	1475
Coarse aggregate	1/2 in. crashed Dolomite	lb/yd^3	1360.0	1360	1360	1360
Fine/Total Aggregate		---	0.52	0.52	0.52	0.52
Water/Cement Ratio		---	0.28	0.7	1.12	1.12
Water/Powder Ratio		---	0.28	0.28	0.28	0.28
HRWR	Plastol 6200 EXT+Plastol 5000	fl oz/cwt	10.35	10.35	10.35	10.35
% of Replacement			0	60	75	75

*Ib/yd^3= 0.593 kg/m^3

FABRICATION AND CURING:

A modified version of ASTM C512 (2010) "Standard Test Method for Creep of Concrete in Compression" was performed to determine the creep of 4x16 in. (100x406 mm) cylinders. Each specimen was placed in 4 x 16 in. (100x406 mm) polyvinyl chloride (PVC) pipes. Concrete was placed in one layer and optionally roded to eliminate any entrapped air voids. Two curing conditions were employed in this study to investigate the effect of curing regimes. For accelerated curing, hot water system was used to simulate steam curing of precast applications. The maximum temperature of concrete was not exceed 158 °F (70 °C) to prevent the risk of delay attringite formation. The temperature rise during accelerated curing was limited to 68°F (20 °C) and also rate of cooling was limited to 68°F (20 °C) in compliance with AASHTO 2007. A preset period of not less than four hours was allowed before accelerated curing was applied. After accelerated regime had been completed, the specimens were demolded and stored in lab temperature room at 70°F (21 °C) until the time of tests. Moist curing specimens were covered with wet jute mats as soon as the concrete had set sufficiently that no marring of the surface or distortion resulted. After 24 hours, they were demolded and then stored into a moist curing room at 73°F (23 °C) temperature with 100 percent relative humidity. After 7 days curing, the specimens were stored in lab temperature room until the day of loading. At 28 days age, DEMEC points were outfitted with five-minute quick set epoxy on the specimens and preliminary readings were taken. Cylinders were loaded to 40 percent of the design strength. Six locations on each cylinder could be read to determine the change in strain over that length. The average of all of the readings was computed to be the total strain of the specimen. Figure 1-a displays the creep specimens setup used in this study.

To measure drying shrinkage, ASTM C157 was followed. A three prismatic specimens measuring 3x3x11.25 in (75x75x285 mm) were performed for each mix with a digital type extensometer as shown in Figure 1-b. The same curing regimes above were conducted for shrinkage specimens. After 7 days, moist curing specimens were stored lab temperature room at 70°F (21 °C). Shrinkage was then measured. However, accelerated curing specimens were demolded after curing and preliminary readings were taken. Table 2 displays concrete curing conditions.

Table 2 Concrete Curing Condition.

Curing Method	Stage	Details
Accelerated Curing	I	Lab Temperature for 4 hours minimum after water-cement contact
	II	Temperature raised for 2 hours
	III	Stead Concrete temperature for 18 hours
	VI	Temperature decreased over 2 hours to lab temperature
	V	Air Curing in Lab Temperature 23 ± 2 °C until testing age
Moist Curing	I	Twenty four hours in molds with wet burlap at 23 ± 2 °C
	II	Moist room curing at 23 ± 2 °C until testing age

a) Creep set up

b) Shrinkage set up

Figure 1 Creep and shrinkage test set up

CREEP AND SHRINKAGE CODE MODELS

Overtime, several models have been proposed to predict creep and shrinkage in concrete structure. In this study, the measured data were compared to typical code models from ACI 209R-09, AASHTO LRFD 2007, and AS3600, to determine whether these equations used by design engineer can be applied to HVSCM-SCC. A brief discussion is presented below. For specific details of the code models, the specific reference should be sought out for review.

ACI 209R (2009)

The ACI 209 model was developed for conventional concrete in 1973 and modified by ACI committee 209 to predict creep and shrinkage at a given age under standard condition and correction factors for other than standard condition. This ACI model considers numerous factors including cement content and type, the aggregate ratio, slump, air content, curing regime and others.

AASHTO LRFD (2007)

The AASHTO LRFD model was based upon work undertaken by Tadros et al. (2003). The research work undertaken by Tadros specifically investigated creep and shrinkage of high-strength concrete since earlier creep and shrinkage models were developed based upon conventional concrete data. The 2007 AASHTO LRFD model, based upon the 2003 study considers volume to surface ratio, relative humidity, and various age and loading aspects respectively.

AS 3600 – 2009

The AS 3600, creep and shrinkage models, includes correction factors for the type of environment, maturity of hardened concrete, and time. The environmental factor considers climates ranging from arid to tropical / near-coastal. Concrete strength is also considered through a basic creep coefficient and calibration factors.

TEST RESULTS AND DISCUSSION

Fresh and hardened properties

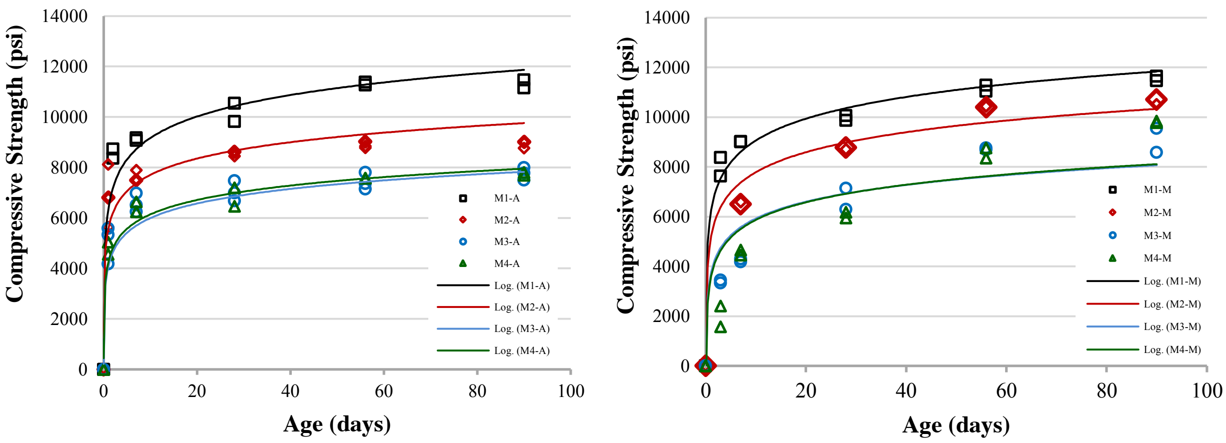
Test results of slump flow, T50, J-Ring, L-Box, density, and temperature are presented in Table 3. The mixtures with SCMs exhibited better rheological properties than 100% cement mixture. Mechanical properties “Compressive strength, modulus of elasticity, tensile splitting, and modulus of rupture”, were conducted according to ASTM specification. Table 4. illustrates the mechanical properties results at 28 days of both accelerated and moist curing regimes. The compressive strength of tested mixtures was monitored at various ages 1, 3, 7, 28, 56, and 3 months as shown in Fig 3. It was found that, in general, each mix developed high early strength for accelerated curing. However, moist curing mixes performed high strength than accelerated over late ages. As anticipated, the compressive strength of HVSCMs mixtures was lower than 100% cement mixture.

Table 3 Measured rheological Properties.

Rheological properties	Unit	Mixtures			
		M1	M2	M3	M4
Slump Flow	in	27.0	26	26	25.5
T50	sec	4.6	2.12	1.87	2.58
J-Ring	in	25.0	23	23	23
T50 (J-Ring)	sec	14.5	4.3	5.3	3.53
L-Box	%	~ 0.8	~ 0.8	~ 0.8	~ 0.8
Air Content	%	1.4	3.4	4.2	4.5
Density	lb/ft^3	153.40	148.8	146.4	145.4
Temperature	F°	65.90	66.9	66.4	65.6

Table 4 Measured mechanical properties at 28 days.

Mechanical Properties	Unit	Mixtures							
		M1		M2		M3		M4	
		Accelerated	Moist	Accelerated	Moist	Accelerated	Moist	Accelerated	Moist
Compressive strength	psi	10187	10059	8572	8595	7054	6720	7034	6305
Tensile splitting test	psi	586	1060	406	400	570	449	549	356
Modulus of elasticity	ksi	6116.7	6866.7	5900	6825	6216.7	6191.7	6050	5950
Modulus of rupture (4x4x14 in Beam)	psi	794	641	1071	724	707	716	832	684



a) Accelerated Curing

b) Moist Curing

Figure 3 Compressive strength results at different curing regimes.

Shrinkage and Creep

Shrinkage and creep reading were taken until age 170 days. As can be seen in Figure 4, total strain of shrinkage and creep together verses elapsed time was drawn for all mixes. In general, it can be interpret that the mixes with high SCM exhibited lower shrinkage values than 100% cement mix. Furthermore, incorporation hydrated lime with binder system reduces the drying shrinkage. However, there was not significant effect on creep results when hydrated lime involves in the binder system. On average, Mix 4 with 75% replacement level exhibited less volume changes than other mixes and that means incorporation of SCMs in the binder system leads to better volume change behaviour.

As shown in Figure 5-a, Moist curing mixes with 75 % replacement exhibited lower drying shrinkage than 60% replacement and mix with 100% cement. Increasing the hydrated lime replacement level and reduce silica fume from 10 to 5 %, reduced drying shrinkage by 20%. Accelerated curing mixes exhibited less drying shrinkage range between 7-50% than drying shrinkage of same mixes cured under moist curing condition as can be seen in Figure 5-b. However, regarding creep results, there was not clear picture about effect the accelerated cuing on creep behaviour.

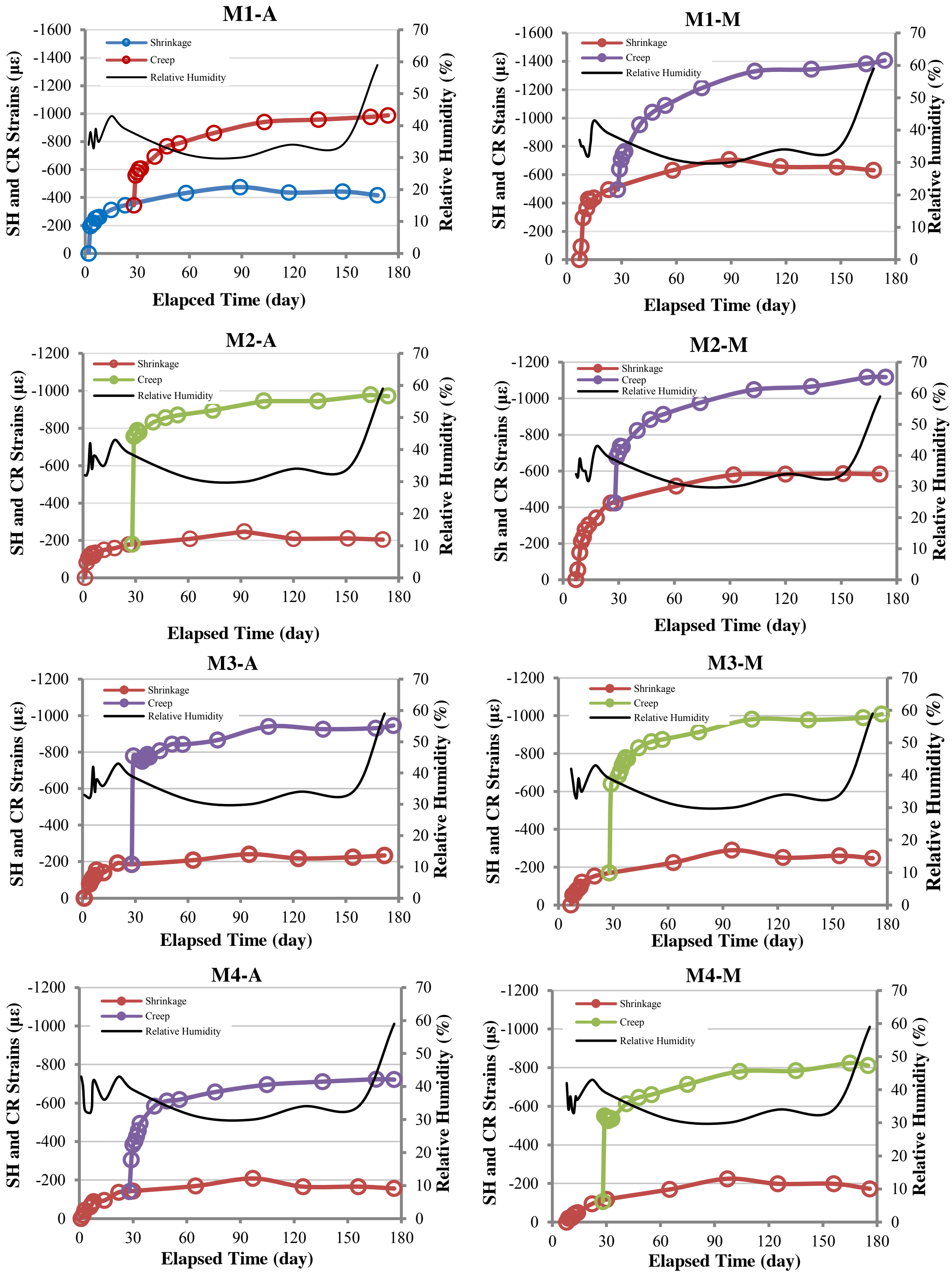
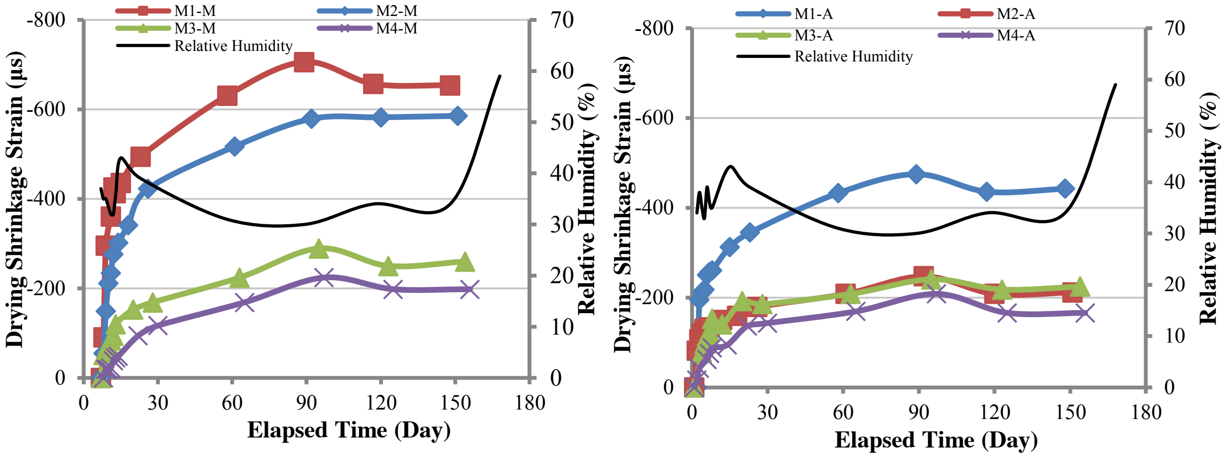


Figure 4 Shrinkage and creep strains vs. elapsed time under different curing regimes



a) Moist Curing b) Accelerated Curing

Figure 5 Drying shrinkage under different curing regimes

Comparison with code models

As shown in Figures 6 and 7, measured drying shrinkage and creep coefficient at age 170 days were compared to empirical code models adopted by ACI-209R, AASHTO LRFD, and AS3600. Mixes M2, M3, and M4 under accelerated curing condition had lower drying shrinkage values than predicted by code models above. In other word, it can be said that, code models overestimated mixes with high volume SCMs. Under moist curing condition, ACI-209R, AASHTO LRFD, and AS3600 overestimated drying shrinkage of mixes with 75% replacement level (M3 and M4). The values obtained by the ACI-209R equations are not as accurate as possible due to the equation requirements and the fact that ACI-209R was developed for conventional concrete. Furthermore, ACI 209R underestimated creep coefficient values of all mixes. In general, it can be indicated that empirical equation of code models were waved to predict the creep coefficient of high volume SCMs concrete.

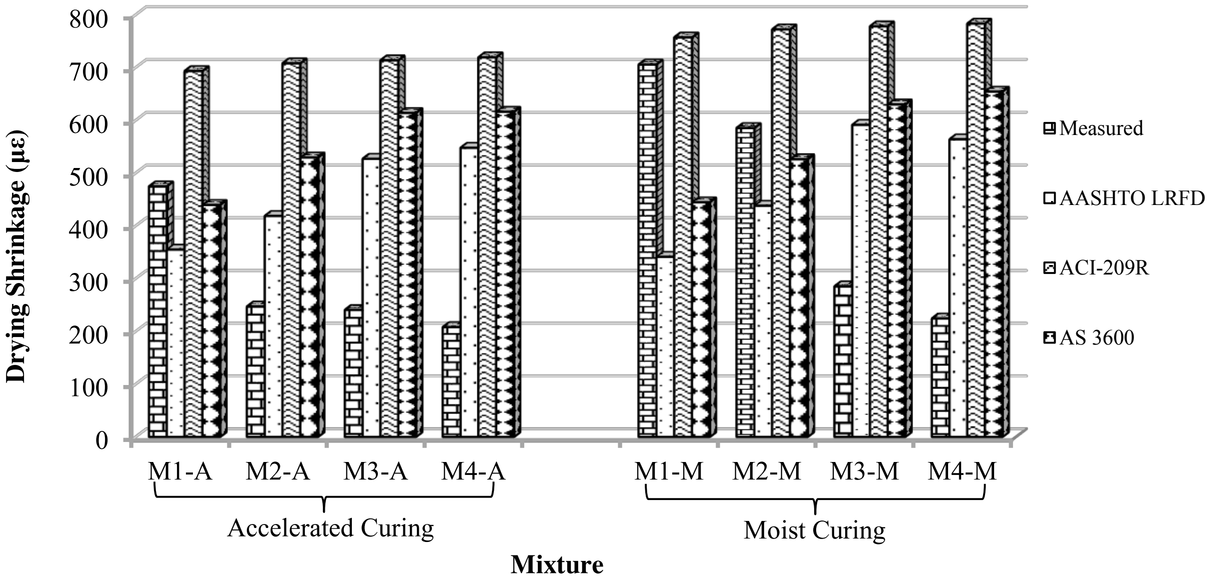


Figure 6 Drying shrinkage at age 170 days under different curing regimes

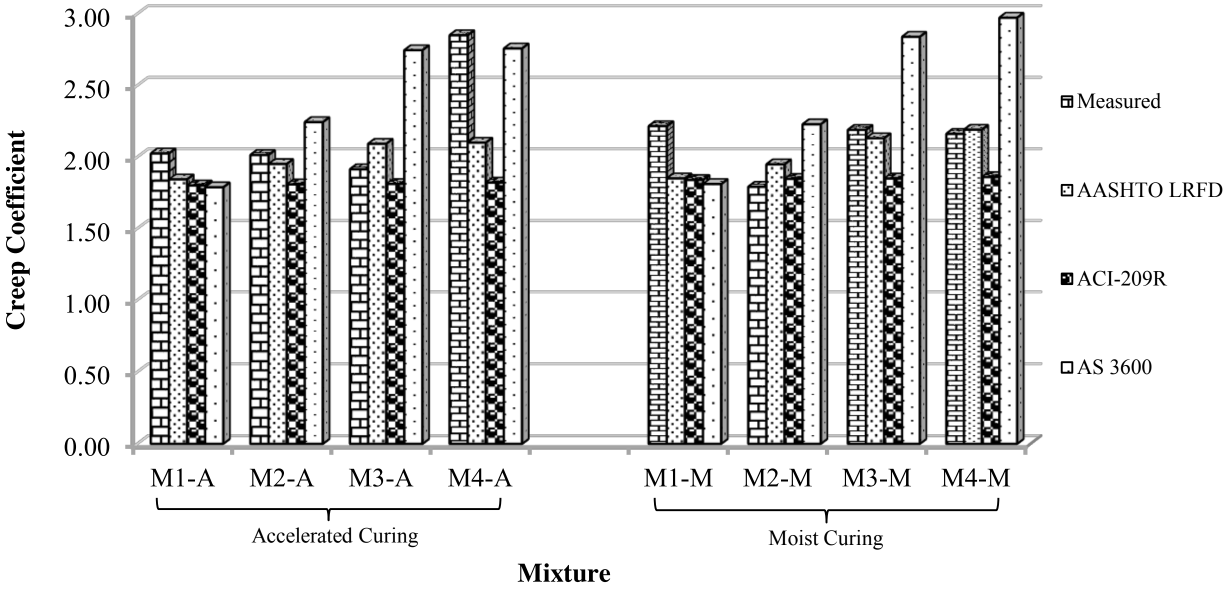


Figure 7 Creep coefficients of mixtures under different curing regimes (at age 170 days)

CONCLUSION

The purpose of this study was to compare volume changing overtime of mixes with different percent of SCMs as cement replacement and see the effect of accelerated curing on creep and drying shrinkage strains. Furthermore, the measured values were compared to the predicted code models adopted by ACI-209R, AASHTO LRFD, and As3600. Based on the results of this study, the following conclusions are presented:

- In this study, Mixes with 75% replacement level exhibited a low level of shrinkage and creep than other mixes.
- For mixes with 75% replacement, increasing the hydrated lime replacement level and reduce silica fume from 10 to 5 %, reduced drying shrinkage by 20%. Reduce in shrinkage is due the fact that lime intend to retain the surplus water of the paste matrix. As result, there is no more free water for drying.
- In general, the highest shrinkage and creep levels were observed in mixes with 100% cement cured under mist curing regimes.
- Accelerated curing mixes exhibited less drying shrinkage range between 7-50% than drying shrinkage of same mixes cured under moist curing condition at 170 days.
- Mixes M2, M3, and M4 under accelerated curing condition had lower drying shrinkage value than predicted by ACI-209R, AASHTO LRFD, and AS3600.
- ACI 209R underestimated creep coefficient values of all mixes due to the equation requirements and the fact that ACI 209 was developed for conventional concrete.

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REFERENCES

American Association of State Highway and Transportation Officials (2007); "*AASHTO LRFD Bridge Design Specifications*;" American Association of State Highway and Transportation Officials; Washington, DC.

American Concrete Institute (ACI 209R-92) (2008); "Prediction of Creep, Shrinkage, and Temperature Effects in Concrete Structures;" *American Concrete Institute*; Detroit, Michigan.

American Concrete Institute (ACI 237R-07) (2007); "Self-Consolidating Concrete;" *American Concrete Institute*; Detroit, Michigan.

American Concrete Institute Committee 232 (2003); "Use of Fly Ash in Concrete" (ACI 232.2R-03). Farmington Hills, MI: *American Concrete Institute*.

AS 3600, 2009. Concrete Structures. Standards Australia.

ASTM C157/C 157M – 08 (2008); "Test method for Length change of hardened Hydraulic-Cement Mortar and Concrete;" *American Society for Testing and Materials*; West Conshohocken, Pennsylvania.

ASTM C 512 – 02 (2010); "Standard Test Method for Creep of Concrete in Compression;" *American Society for Testing and Materials*; West Conshohocken, Pennsylvania.

Brewe, Jared E.; Myers, J.J. (2010); "High-Strength Self-Consolidating Concrete Girders Subjected to Elevated Fiber Stresses Part I: Prestress Loss and Camber Behavior;" *Prestress/Precast Concrete Journal; Chicago*, Illinois; Fall 2010; Vol. 55 No.4; pp 59-77.

Daczko J. A; "Self Consolidation Concrete, Appling What We Know;" 1st. ed. Spon Press, Abingdon, Oxon. 2012.

Fennis, S.A.A.M. and Walraven, J.C. (2011); "Ecological Concrete and Workability: A marriage with Future;" *36th Conference on Our World in Concrete & Structures Singapore, August 14-16, 2011*; http://cipremier.com/100036007.