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PREDICTION MODEL FOR SHRINKAGE OF LIGHTWEIGHT AGGREGATE CONCRETE

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ABSTRACT

Volumetric change due to shrinkage affects performance of structural concrete thorough its service life. Prediction model that could be employed to estimate shrinkage after years will be beneficial for designer in analysing such effect. Unfortunately, the existing prediction model for example ACI 209R-92 is developed for normal weight concrete. The validity of the model for estimating shrinkage of lightweight aggregate concrete (LWAC) is in question. This research is aimed to improve ACI 209R-92 model that will be applicable for predicting shrinkage of LWAC. For this purpose, measurement of shrinkage of LWAC up to 585 days on specimens with various curing periods were carried out. ACI 209R-92 model is utilized as starting point for the prediction of shrinkage of LWAC and then shrinkage half time value used in the model is modified to fit with the measurements. The proposed model is confirmed by the results of other investigators. It is shown that prediction of long-term shrinkage of LWAC could be improved when shrinkage half time used in ACI 209R-92 model is 65 instead of 35.

Keywords: Lightweight aggregate concrete; model; prediction; shrinkage

1. INTRODUCTION

The dead load of concrete building composes a significant portion of the total gravity loads that have to be supported by the structural elements. Reducing the mass of structure or building by the use of lightweight concrete offers advantageous in reducing section of elements. Furthermore, as earthquake forces, which affect the performance of structure, are proportional to the mass of the structure, reduction in the mass of the structure will lessen its seismic risk. LWAC has been successfully applied in construction of Wellington Stadium in New Zealand [1] and Chickahominy River Bridge [2]. The growing interest in the use of LWAC raises concern over its long-term performance in relation to shrinkage. Shrinkage affects performance of structural concrete in a variety of ways: it contributes to loss of prestressing in prestressed concrete structure; it creates considerable long-term deflection, etc.

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Neville and Brooks [3] notes that LWAC exhibits higher shrinkage than concrete made with normal aggregate. This is also confirmed by the results of Kayali et al. [4]. Zhang et al. [5] observe LWAC initially shrinks below that of normal concrete but eventually reaches over the shrinkage of normal concrete. On the other hands, Fujiwara [6], Asamoto et al. [7] and Imamoto and Arai [8] remarks that shrinkage of LWAC is comparable or even less than that of normal concrete. The fact that LWAC shows evidence of difference magnitude of shrinkage in comparison to that of normal concrete should be taken into account by designer in analysing the effect of shrinkage on structural concrete made of lightweight aggregate.

The computation of long-term effect of shrinkage will be possible when its long-term value could be determined. It is common practice to determine long-term shrinkage by assumption or prediction using relevant model. The existing models for estimating long-term shrinkage are not strictly applied for determining long-term shrinkage of LWAC since they are developed for normal concrete [2,9]. The need for the development of prediction model suitable for estimating shrinkage of LWAC becomes insistent.

It is accepted that shrinkage has limiting value. For this reason, mathematical models that could be used to express shrinkage behaviour are in the form of exponential or hyperbolic-power types. ACI 209R-92 adopts the later type as follows:

$$\varepsilon_{sh(t)} = \frac{t}{35+t}\varepsilon_{sh(\infty)} \tag{1}$$

where $\varepsilon_{sh(t)}$: shrinkage at time t (days),

$\varepsilon_{sh(\infty)}$: ultimate shrinkage,

t : time since drying (days)

The model assumes shrinkage half time equals to 35 for moist curing suggesting that the magnitude of shrinkage attains a half of the ultimate value at 35 days of drying. Shrinkage behaviour observed in LWAC is similar in trend to that of normal concrete. Its magnitude increases at diminishing rate over time. It is reasonable, therefore, to express the shrinkage behaviour of LWAC with equivalent model to that of normal concrete. The development of prediction model proposed in this research is based on the formulation of ACI 209R-92 and then it is improved by setting different value of shrinkage half time that fit the experimental data by mean of coefficient error. The equation that may be applied to determine the error coefficient (M) is as follows [10]:

$$M = \frac{1}{\bar{\varepsilon}_{sh(t)}}\sum\left\{\frac{\left[\varepsilon_{sh(t)} - \varepsilon'_{sh(t)}\right]^2}{n}\right\}^{1/2} \tag{2}$$

where $\varepsilon_{sh(t)}$ = measured shrinkage at given time t

$\varepsilon'_{sh(t)}$ = predicted shrinkage value at given time t

$\bar{\varepsilon}_{sh(t)}$ = mean of measured shrinkage

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n = the number of measured shrinkage

Based on the lowest coefficient error, a new value of shrinkage half time is proposed to modify ACI 209R-92 model. The modified ACI 209R-92 model is then applied to estimate long-term shrinkage of LWAC from the results of others. The proposed model shows improvement in estimating shrinkage of LWAC compared to the original model of ACI 209R-92.

2. EXPERIMENTAL WORKS

2.1 Materials, mix proportions and fundamental properties

The artificial lightweight aggregate (ALWA) used for producing LWAC is expanded clay type manufactured from PUSKRIM, Cilacap, Indonesia. The water absorption of ALWA is about 15% and its bulk specific gravity is 1.65. All the aggregates are conformed to the relevant ASTM standards. The mix proportions used in this research including a variety of curing periods of the specimens are given in Table 1. All aggregates are in saturated surface dry (SSD) condition prior to mixing. The fundamental properties of LWAC are presented in Table 2.

Table 1. Proportion of mix for a batch of 1 m^3 LWAC.

Specimen Identification	Cement (kg)	Sand (kg)	ALWA (kg)	Water (kg)	Curing Period (days)
LWAC – 1	519	334	837	207	1
LWAC –3	519	334	837	207	4
LWAC – 7	519	334	837	207	7
LWAC – 14	519	334	837	207	14
LWAC –21	519	334	837	207	21
LWAC –28	519	334	837	207	28

Table 2. Fundamental properties of LWAC

Slump	195 mm
Density	1800 kg/m^3

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Compressive strength	20 MPa

2.2 Measurement of shrinkage

The specimens having size of 75 mm in diameter and 276 mm in length were prepared for shrinkage measurement. At least two specimens were used for each type of curing period in order to determine the shrinkage. Prior to testing, the specimens were stored in water for a variety of period (see Table 1). Four pairs of demec points at gauge length of 200 mm were attached on the surface of each specimen and the change in length of the demec points in time were determined using Demec Gauge. All measurements were performed in the laboratory environment with temperature in the range of 25-32^{o}C and relative humidity of 60-70%.

3. PREDICTION MODEL FOR SHRINKAGE OF LWAC

Figure 1 shows the results of shrinkage measurement of LWAC. It is shown in the figure that longer period of curing tends to reduce shrinkage of LWAC. This could be attributed to the fact that longer curing period gives the chance for LWAC to develop its hardened properties which are beneficial to enhance its capacity to restrain the shrinking of concrete.

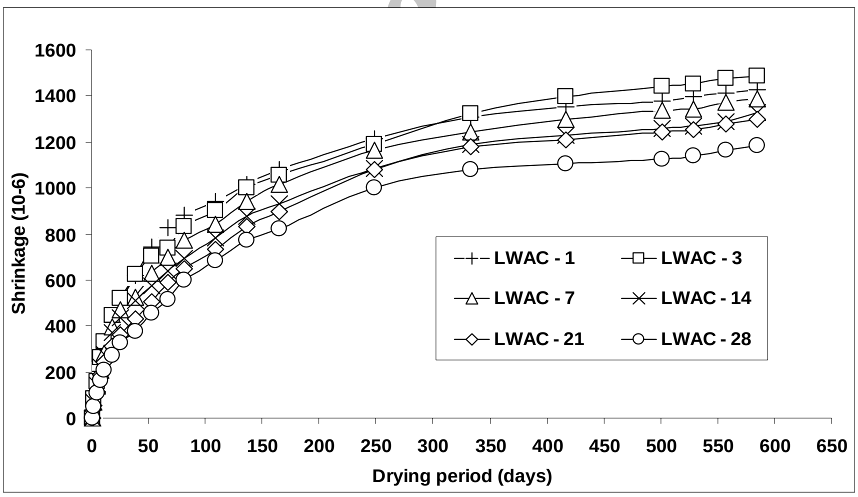

Figure 1. Shrinkage of LWAC with a variety of curing periods observed in the current research

Figure 2 gives illustration of ACI 209R-92 prediction model that has been applied to estimate shrinkage of LWAC of this research. It is expected that the values of estimated shrinkage deviate from the measured shrinkage of LWAC. At early time ACI 209R-92 can predict the shrinkage of LWAC quite well but later on the predictions start showing deviation. For all specimens the deviations show similar pattern: the prediction model

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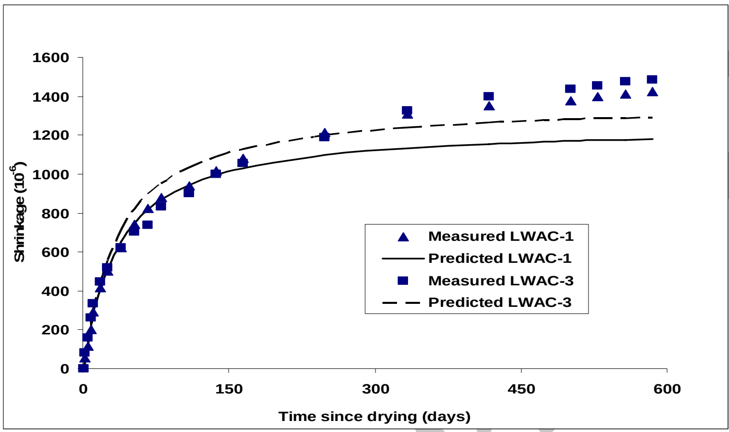
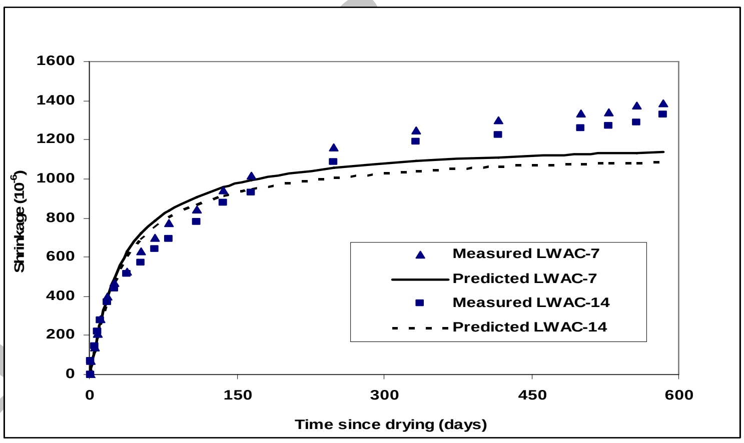
underestimates the measured values and as time increases the difference in magnitude is more pronounce. It is also shown that curing period affects the accuracy of prediction: longer curing period tends to increase the difference between measurement and prediction. The accuracy in prediction is quantitaively determined using Eq.2 and the calculated coefficient error in predictions are given in Table 3. As shown in Table 3 coefficient errors in predictions are relatively high (on average 57%) even though higher coefficient error is also common when ACI 209R-92 model is applied for normal concrete [11].





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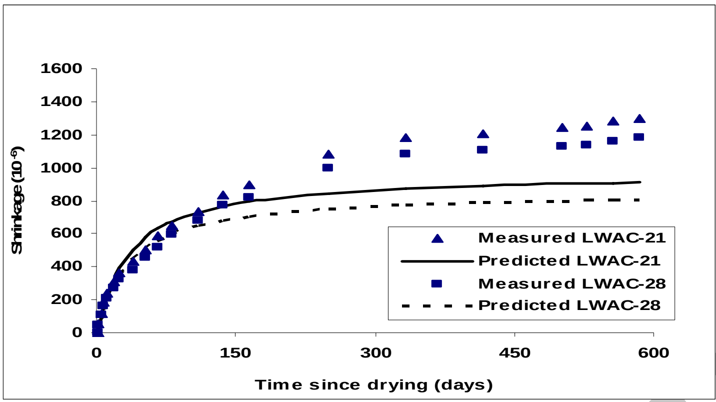

Figure 2. Comparison between measured shrinkage of LWAC observed in the current research and their predicted values using ACI 209R-92 model

Table 3. Coefficient error in prediction when ACI 209R-92 model is applied to LWAC.

Specimen	**Coefficient error (%)**
LWAC-1	38,9
LWAC-3	54,6
LWAC-7	54,7
LWAC-14	60,1
LWAC-21	77,9
LWAC-28	79,6

Attempts have been made by many investigators to improve the prediction. Almudaiheem and Hansen [11] suggest ACI 209R-92 model may be modified by using variable N to substitute shrinkage half time of 35 days. They argue variable N could correct the error due to size effect. Another improvement has been early suggested by Bryant and Vadhanavikkit [12]. In their model, size effect is rectified not only by proposing a change in shrinkage half time but also suggesting integration of size effect parameter into time of drying. Meanwhile, Karthikeyan et al. [13] explore the use of artificial neural network to improve CEB 90 model prediction by taking into account relative humidity, volume surface ratio, compressive strength and time at which shrinkage is measured.

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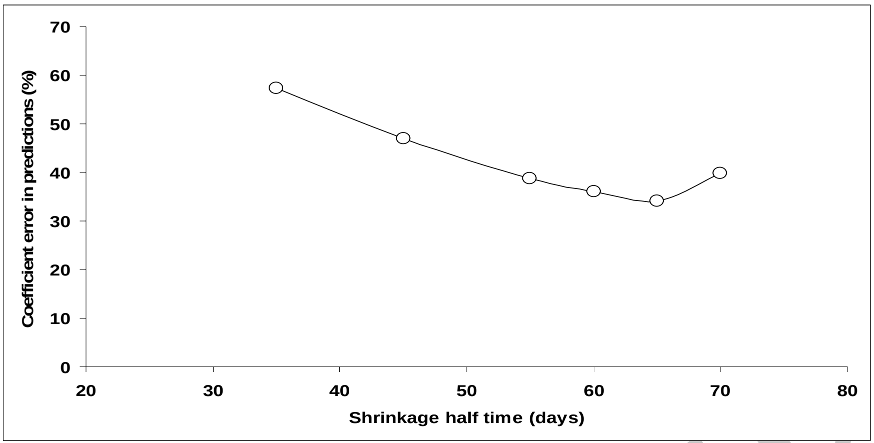

Figure 3. Varying shrinkage half time influences coefficient error in prediction

It should be noted that ACI Committee 209 [14] recommends their prediction model to be used in the absence of specific data which affect shrinkage behaviour. In line with this recommendation, the current research adopts a simple approach to improve the prediction of shrinkage of LWAC without taking into account variety of parameters which affect shrinkage behaviour of LWAC. The approach is as follows: different values of shrinkage half time ranging from 35-70 days were applied and their corresponding coefficient errors were calculated. Evaluation of the coefficient errors as indicated in Figure 3 suggests if shrinkage half time of 65 days is applied to ACI 209R-92 model prediction; it will give the lowest coefficient error. A reduction in coefficient error of up to 40% is obtained when a value of shrinkage half-time of 65 is employed to substitute 35 days. Hence, ACI 209R-92 prediction model may be modified by turning a value of shrinkage half time into 65 days.

4. VALIDITY OF THE PREDICTION MODEL FOR SHRINKAGE OF LWAC

The proposed modification of ACI 209R-92 model with introduction of new shrinkage half time value of 65 days is then applied to estimate shrinkage of LWAC observed by other investigators. The specimen type, curing period, drying environment and compressive strength of their LWAC are summarized in Table 4. The variety of specimen properties and conditions are selected in the evaluation of the proposed modification of ACI 209R-92 model for the reason that the prediction model should be applicable for various circumstances. In other words, the modified ACI 209R-92 model may be applied in the absence of specific data. The results of prediction are compared to those predicted by the original ACI 209R-92 model in term of coefficient error (see Table 5). Generally the proposed modification model shows improvement in prediction as it reduces coefficient error by 10 to 55% with the exception of Reinhardt and Kummel's. Even though higher error is found for the results of Reinhardt and Kummel [15], but the absolute value of error is still within acceptable level. It has been suggested by Gomez and Landsberger [16] that the expected error prediction of the existing models for estimating shrinkage of concrete

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could be up to 50%.

Table 4. Data of specimens used to validate the proposed model

Source of data	Specimen* (dimension in mm)	Curing prior drying	Drying environment	Compressive strength
EuroLightCon [9]	50 x50 x 200	sealed for 14 days	20^{o}C; 50% RH	75 MPa
EuroLightCon [9]	50 x50 x 200	sealed for 28 days	20^{o}C; 50% RH	75 MPa
Reinhardt & Kummel [15]	100 x 300	stored in fog room (100% RH) for 6 days and then move to 65%RH until age of 28 days	20^{o}C; 65%RH	15 MPa
Zhang et al.[5]	100x100x400	moist curing for 7 days	30^{o}C; 65%RH	50 MPa
Lopez et al.[17]	100x380	stored in foog room for 28 days	23^{o}C; 50%RH	75 MPa
Fajardo et al.[18]	100x100x400	NA	NA	20 MPa
Imamoto & Arai [8]	100x100x400	stored in water for 7 days	20^{o}C; 60%RH	30 MPa
Current research	75x275	various stored in water for 1, 3, 7, 14, 21 and 28 days	25-32^{o}C; 60-70%RH	20 MPa

* The dimension of specimens are either prisms or cylinders

Table 5. Comparison of coefficient error between predicted shrinkage based on original and modified ACI209R-92

Source of data	Coefficient error (%)	
	Original ACI 209R-92	Modified ACI209R-92
EuroLightCon [9]	23,2	17,9
EuroLightCon [9]	42,8	19,4
Reinhardt & Kummel [15]	14,4	27,6
Zhang et al. [5]	81,7	47,1
Lopez et al. [17]	26,7	19,0
Fajardo et al. [18]	58,6	52,7
Imamoto & Arai [8]	45,8	22,7
Current research	57,0	34,1

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5. CONCLUSIONS

Modification of ACI 209R-92 model is proposed to estimate shrinkage of LWAC by substituting shrinkage half time value from 35 to be 65 days. The modified model could be applied for general conditions or in the absence of specific data. A reduction in coefficient error ranging from 10 to 55% may be expected in comparison to prediction using the original ACI 209R-92 model.

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