



Comparison of Drying Shrinkage Models of ICI Concrete

Oritala, S. P.¹, Saleh, A. U.², Mohd Han, A. R.³, Mubarek, W. & Aliyas, B.

^{1,2,3} Civil Engineering Department, Federal University of Technology, P.M.B. 70, Owerri, Niger State, Nigeria

² Department of Materials and Structures, Faculty of Civil Engineering, Universiti Teknologi Malaysia, 81300 Skudai, Johor, Malaysia

³ Department of Materials and Structures, Faculty of Civil Engineering, Universiti Teknologi Malaysia, 81300 Skudai, Johor, Malaysia

*Corresponding author email: soritola@futo.owerrinigeria.gov.ng

ABSTRACT

Problems associated with drying shrinkage of concrete is still a major source of concern in the construction industry. Due to the hygral nature of concrete, particularly the mobility of the moisture in a result of drying shrinkage, concrete will crack at any stage during its service life. The expansion of the environment due to huge consumption of sand for construction is another major problem. Iron ore tailings (IOT), an industrial waste generated during the production of iron ore is utilized in concrete to reduce the environmental problems. The iron ore tailings was crushed into a mesh iron ore producing sludge and the material was used in partial replacement for sand in produce normal weight concrete. The drying shrinkage of this concrete was compared with that of the control normal weight concrete. The ultimate drying shrinkage of the concrete samples were further studied using three prediction models. The inclusion of iron ore tailings as fine aggregate in concrete contributed a reduction of the drying shrinkage recorded at 28, 56 and 90 days as well as the ultimate drying shrinkage. The drying shrinkage of concrete and the predicted ultimate drying shrinkage recorded by the B3 and GL2000 models agreed more closely, in comparison with the recorded values obtained using ACI209R model.

Keywords: Drying shrinkage prediction, Environment sustainability, Fine aggregate, Iron ore tailings, and Normal weight concrete.

1 INTRODUCTION

Design of concrete that considers shrinkage model is significant for long period durability of concrete structures. Presently, little attention is given to the phenomenon of drying shrinkage of concrete and this is responsible for most of the damages on concrete structures due to creep and shrinkage. Majority of these problems become noticeable after thirty years or more, of the structure service life. Also very few experimental data that describe more than two years drying shrinkage of concrete are available from various laboratories, based on available resource from database. It is therefore necessary to predict the drying shrinkage of concrete members by theoretical extrapolation of time.

Due to the hygral behaviour of concrete, it is very necessary to determine experimentally, the effects of any form of material on the properties of the concrete, to be certain of its influence on the mechanical features. This necessity becomes of paramount importance, when a new material such as iron ore tailings is being considered. Tar et al. (2008) stated that, the specific impact of any set of materials on the shrinkage of concrete should be determined by laboratory testing. Several attempts and

methods have been used in the past to reduce drying shrinkage of concrete. Some of this includes using the maximum practicable amount of aggregate in the mix, reduction of water-to-cement ratio and adjustment of water content when placing concrete during casting. Previous studies have also explored several ways to reduce the phenomenon of shrinkage in concrete by altering the fine and coarse aggregate content of concrete. Singh et al. (2005), Gnanaprakasam et al. (2011), Tarat et al. (2006). Drying shrinkage of concrete containing iron ore tailings was found to be lower than those of the concrete prepared with only river sand. Gnanaprakasam et al. (2004) also reported that the drying shrinkage of concrete containing iron ore tailings at replacement percentage of 20, 40, 50 and 60% were less than those of concrete containing iron ore sand. Their study concluded that the drying shrinkage of the tested concrete increases with the increase in iron ore tailings content.

The prediction of performance of concrete members using models and comparing with experimental results can assist in better assessment of structural members. In support of this, one of the models studied in this research, the B3 model was developed using one thousand eight hundred and nine (1809) drying shrinkage of concrete

experimental results (Havlascek and Jirasek, 2016). The outcomes of experimental tests carried out using iron ore tailings as fine aggregate to partially replace sand in normal strength concrete and the effect on the drying shrinkage are presented in this study. The prediction of the development and extent of shrinkage in concrete were evaluated based on models developed by the American Concrete Institute (ACI 209R, 1994), Bazant and Baweja B3 (Bazant and Baweja, 2000) and GL2000 (Gardner and Lockman, 2001). The ultimate drying shrinkage of concrete determined using these models were compared. The prediction of long term performance of concrete structures tends to ensure sustainability of the construction industry and better future for the national economy.

2 METHODOLOGY

The procedure of this study involves experimental determination of drying shrinkage of concrete that contains iron ore tailings as partial replacement for sand in concrete. The drying shrinkage of this concrete was compared with that of the control normal weight concrete. In order to validate the outcome of the experiments, the drying shrinkage strains were compared with a model recommended by design code, the American Concrete Institute ACI 209R-94. The shrinkage strains were further analyzed using academic models developed by Bazant and Baweja, (2000) B3 and GL2000 (Gardner and Lockman, 2001).

2.1 MATERIALS

The concrete samples used for experimental studies are described by Figure 1 and Figure 2. The normal weight concrete produced using conventional aggregates is denoted as CT0 while those that contains 30% of iron ore tailings as partial replacement for sand as fine aggregate in concrete is denoted as CZT30.

CT0



- Water 250kg/cum
- Cement 473kg/cum
- Crushed Granite 868 kg/cum
- Sand 769 kg/cum

Figure 1. Composition of CT0 Concrete Sample

CZT30



- Water 250kg/cum
- Cement 473kg/cum
- Crushed Granite 868 kg/cum
- Sand 538 kg/cum
- IOT 231 kg/cum

Figure 2. Composition of CZT30 Concrete Sample

2.2 DETERMINATION OF DRYING SHRINKAGE OF IOT CONCRETE

The procedure described in the American Society for Testing of Materials guidelines ASTM C157, (2013) was used to determine the drying shrinkage of concrete



samples. The change in length of concrete prism samples were determined at 1, 7, 28, 56 and 90 days, for the purpose of evaluating the expansion and drying shrinkage. For each type of concrete sample, the average of four concrete prisms results were used for the determination of the concrete strains.

The length change in concrete prisms specimens was determined using mechanical extensometer. The design of the mechanical extensometer is based on the principle that two rigid bodies will exhibit degrees of freedom relative to each other. Two visual point connections were used between the instrument and the specimen. The translational freedom between the connections was provided by a moving arm pivoting about a knife-edge and button seating. The instrument was held with the moving point of the knife-edge in the right hand. The shrinkage readings were digitally displayed on the screen. The concrete strain was calculated from the relationship expressed in Equation 2.1.

$$\text{Strain} = \frac{\text{Change in Length}}{\text{Original Length (Gauge Length)}} \quad (2.1)$$

2.3 ACI 209R-94 MODEL

The shrinkage model is for any period and it is a linear function of the ultimate values. The parameters that were considered in developing the equations are the age of concrete at the end of moist curing, ambient relative humidity, average thickness, concrete slump, fine aggregate content, air content, cement content and type. In the ACI model, the shrinkage strain is expressed by (2.2).

$$E_{sh}(t, t_c) = \frac{(t-t_c)^\alpha}{f + (t-t_c)^\alpha} \cdot E_{shu} \quad (2.2)$$

Where,

- $E_{sh}(t, t_c)$ = Shrinkage strain
- t = Age of concrete (days)
- t_c = Age of concrete at the end of curing (days)
- f and α = Time-ratio constants
- E_{shu} = Ultimate shrinkage strain

2.4 BAZANT-BAWEJA B3 MODEL

The B3 model lays much emphasis on theory and it is restricted to concrete produced using the Portland cement, with water-cement ratio range of 0.35 – 0.85, aggregate - cement ratio of 2.5 to 13.5, cylinder compression strength of 17 – 70 MPa and cement content of 160 – 720 kg/m³. The parameters considered in developing the equations are the age of concrete at the end of moist curing, relative humidity, effective cross-section thickness, aggregate content, water content, cement content and type, curing condition, concrete mean compressive strength and modulus of elasticity. The mean shrinkage in the cross section of concrete is depicted by (2.3).

$$E_{sh}(t, t_c) = -E_{shu}K_h S(t - t_c) \quad (2.3)$$

Where,

- $E_{sh}(t, t_c)$ = Mean shrinkage strain
- t = Age of concrete (days)
- t_c = Age of concrete at start of drying (days)
- E_{shu} = Ultimate shrinkage strain
- K_h = Humidity dependence factor
- $S(t - t_c)$ = Time curve

Equation (2.4) expresses the ultimate shrinkage E_{shu} .

$$E_{shu} = -E_{su} \frac{E_{cm507}}{E_{cm}(t_c + \tau_{sh})} \quad (2.4)$$

Where,

- E_{su} = $-\alpha_1 \alpha_2 [0.019w^{21} f_{cm28}^{-0.28} + 270] \times 10^{-6}$
- w = Water content (kg/m³)
- f_{cm28} = 28 days mean compressive strength (MPa)
- α_1 = Constant related to cement type
- α_2 = Constant related to curing condition

$$\frac{E_{cm507}}{E_{cm}(t_c + \tau_{sh})} = \text{Time dependence factor of shrinkage}$$

This is further defined by (2.5).

$$E_{cmt} = E_{cm28} \left(\frac{t}{4+0.85t} \right)^{0.5} \quad (2.5)$$

The time function for shrinkage $S(t - t_c)$ is defined by (2.6),

$$S(t - t_c) = \tanh \left(\frac{t - t_c}{\tau_{sh}} \right) \quad (2.6)$$

Where,

τ_{sh} = Shrinkage half-time in days

$$\tau_{sh} = 0.085 t_c^{-0.08} f_{cm28}^{-0.25} [2k_s (V/S)]^2 \quad (2.7)$$

- k_s = Cross section shape correction factor
- V/S = Volume-surface ratio (mm)

2.5 GL2000 MODEL

The model is designed for calculating the shrinkage of normal strength concrete with mean compressive strength less than 82 MPa. The stiffness of the aggregate is taken into consideration by using the mean of the cylinder strength and the measured modulus of elasticity of the concrete. The parameters that were used in developing the drying shrinkage equations are the age of concrete at the end of moist curing, concrete mean compressive strength, and modulus of elasticity, relative humidity and volume-surface ratio. Equation (2.8) depicts the shrinkage strain $E_{sh}(t, t_c)$ of concrete as developed by the model.

$$E_{sh}(t, t_c) = E_{shu} \beta(h) \beta(t - t_c) \quad (2.8)$$

Where,

t = Age of concrete



- t_c = Age at start of drying (days)
 E_{shu} = Ultimate shrinkage strain
 $\beta(h)$ = Correction for humidity effect
 $\beta(t - t_c)$ = Correction for drying period

The ultimate shrinkage E_{shu} is expressed by (2.9),

$$E_{shu} = 900k \left(\frac{20}{f_{cm28}} \right)^{0.5} \times 10^{-6} \quad (2.9)$$

Where,

- k = Shrinkage constant for type of cement
 f_{cm28} = Mean compressive strength of concrete

The effect of relative humidity is corrected by the expression (2.10),

$$\beta(h) = 1 - 1.18h^4 \quad (2.10)$$

Time function for shrinkage $\beta(t - t_c)$ is expressed by (2.11),

$$\beta(t - t_c) = \left[\frac{(t - t_c)}{(t - t_c) + 0.12(v/s)^2} \right]^{1/2} \quad (2.11)$$

Where,

- v/s = Volume-surface ratio

3 RESULTS AND DISCUSSION

Most of the important properties of hardened concrete are related to the quantity and the characteristics of the various types of materials in the concrete. The contribution of iron ore tailings to the dimensional stability of concrete are discussed in this section. The drying shrinkage of concrete as described by three models are compared in relation to results obtained from experiments.

3.1 EXPANSION AND SHRINKAGE OF CONCRETE

The expansion and drying shrinkage of concrete in relation with the age of concrete, for the control concrete sample CT0 and the sample which contains iron ore tailings as partial replacement for sand CZT30 is shown in Figure 3. The concrete samples were cured in water for 7 days. As a result of this the concrete expands due to water absorption by the cement gel. This swelling of the concrete is reflected by the peak of the curve in Figure 3. The concrete sample containing iron ore tailings were characterized with reduced drying shrinkage after 90 days storage at laboratory temperature and relative humidity as compared with the control. Since all other factors were kept constant except the fine aggregate content for the concrete mixture, it implies that the iron tailings is responsible for the decrease in drying shrinkage of CZT30.

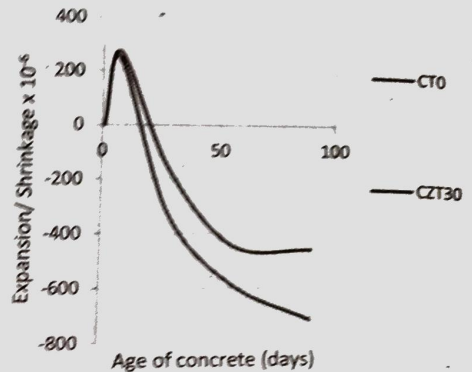


Figure 3: Expansion and Shrinkage in relation with age of Concrete

3.2 ANALYSIS OF DRYING SHRINKAGE BASED ON ACI MODEL

The relationship between the drying shrinkage and age of concrete as derived from experiment and ACI-209R model is shown in Figure 4. The recorded values of drying shrinkage for the control concrete CT0 and those of CZT30 are the same based on the ACI-209R equation. The reason for this, being that, differences in the recorded values of parameters, namely slump of concrete and air content, have insignificant effect on the final value of the drying shrinkage of concrete, using the ACI-209R equation. The values of other parameters considered, the ambient relative humidity, average thickness, fine aggregate content, cement content and type of cement are the same for both concrete based on the experimental design. The estimated drying shrinkage values obtained from the model are significantly lower compared to the experimental recorded values for both concrete.

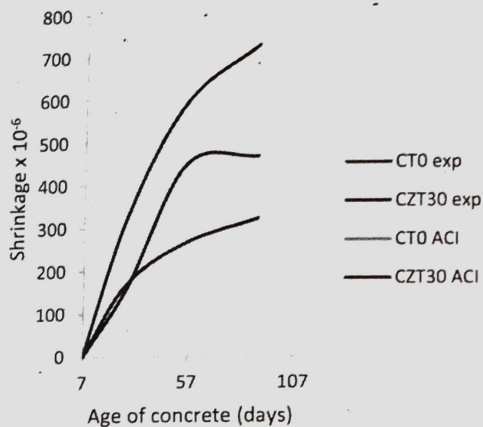


Figure 4: Drying shrinkage curves of concrete based on experiment and ACI model

3.3 ANALYSIS OF DRYING SHRINKAGE BASED ON B3 MODEL

The relationship between the drying shrinkage and age of concrete based on experimental results and Bazant-Baweja B3 model is shown in Figure 5. Although the estimated drying shrinkage values obtained from the model are considerably lower compared to the experimental data for the control and the IOT concrete, the predicted values followed the same trend with the experimental results. Also the concrete mean compressive strength factor in the model, contributed much to the drying shrinkage evaluation, but the effect is not as significant compared to the GL2000 model.

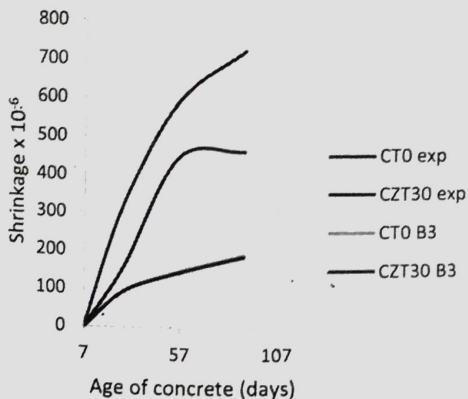


Figure 5: Drying shrinkage curves of concrete based on experiment and model B3

3.4 ANALYSIS OF DRYING SHRINKAGE BASED ON GL2000 MODEL

The relationship between the drying shrinkage and age of concrete as obtained from experiment and GL2000 model is shown in Figure 6. The Figure clearly shows that the estimated drying shrinkage values obtained from the model are considerably lower compared to the experimental data for the control and the IOT concrete. The predicted values however, followed the same trend with the experimental results. The IOT concrete recorded lower values of drying shrinkage compared to the control concrete. The concrete mean compressive strength is a major parameter in the model, as regards the determination of the drying shrinkage.

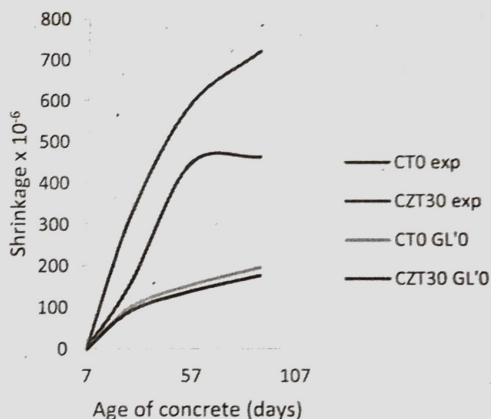


Figure 6: Drying shrinkage curves of concrete based on experiment and model GL2000.

3.5 ULTIMATE DRYING SHRINKAGE OF IOT CONCRETE

The ultimate drying shrinkage for the IOT concrete CZT30, compared with the control concrete CT0, is presented in Table 1. The shrinkage values were evaluated from the equations developed from the three models considered in this study. According to models B3 and GL2000 the predicted values for the IOT concrete are lower by 4.2% and 10% compared to the control concrete.

The value predicted by ACI209R model is clearly out of range in comparison with the other models. Similar deduction was made in the study carried out by Bazant et

al., (2015). The out of fit result recorded by ACI209R could be due to the fact that, there has not been much improvement on the model for quite some time. Also the ACI209R did not include the concrete mean compressive strength among the factors considered in developing the model. The concrete mean compressive strength is a major contributing factor in the B3 and GL2000 models. It recorded significant effect on the values of concrete shrinkage strains. The correlation of predicted ultimate shrinkage as recorded by the three models compared is shown in Figure 7. The control concrete recorded correlation of 0.42 while the IOT concrete recorded 0.3.

The weak correlation among the models based on ultimate shrinkage values recorded by the concrete samples can be attributed to the significantly low value of ultimate drying shrinkage predicted by the ACI209R model. This observation was also reported in the study carried out by Havlásek, and Jirásek, (2016).

Table 1: Predicted ultimate drying shrinkage of concrete

Ultimate drying shrinkage of concrete x 10⁻⁶

Models	CT0	CZT30
ACI209R	453	453
B3	1027	984
GL2000	829	746

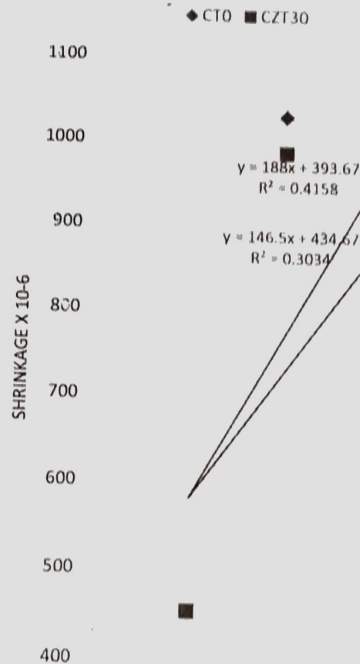


Figure 7: Correlation of predicted ultimate shrinkage among the models

4 CONCLUSION

Due to the texture of iron ore tailings, it can be used in concrete as fine aggregate to reduce the drying shrinkage of normal strength concrete. The constituent materials and the concrete mean compressive strength are major contributing factors to be considered in developing a workable model to estimate the drying shrinkage of concrete. The drying shrinkage of concrete should be experimentally determined and compared with models in all occasions, to guard against future concrete deterioration. The ACI209R underestimate the future drying shrinkage of concrete. In terms of industrial application, the IOT concrete can be used in construction where there is need to improve the dimensional stability of the concrete.

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