**Comparison of Drying Shrinkage Models of IOT Concrete**

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| ABSTRACT  Problems associated with drying shrinkage of concrete is still a major concern in the construction industry. Due to the hygral nature of concrete, particularly the instability of the volume as a result of drying shrinkage, concrete will crack at any stage during its service life. The depletion of the environment due to huge consumption of sand for construction is a major problem. Iron ore tailings (IOTs), an industrial waste, generated during the production of iron ore is utilized in concrete to alleviate environmental problems. The iron ore tailings were sourced from five different mines to produce five types of normal weight concrete. The drying shrinkage of these concrete were compared with that of the control normal weight concrete. The ultimate shrinkage of all the concrete samples were further studied, using three prediction models. The inclusion of iron ore tailings in concrete contributed to reduction of drying shrinkage. The prediction of the ultimate drying shrinkage of IOTs concrete based on the analysis of three models revealed  Keywords: *Drying shrinkage prediction, Environment sustainability, Fine aggregate, Iron ore tailings, Normal weight concrete.* |

# 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 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. Tarr *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 reported several ways to reduce the phenomenon of shrinkage in concrete by altering the fine and coarse aggregate content of concrete (Singh *et al.,* 2015; Zhang *et al.,* 2014; Gholamreza *et al.,* 2011; Tarun *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 (Zhang *et al.,* 2014). Guodong *et al.* (2014) 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 only river sand. Their study concluded that the drying shrinkage of the tested concrete decreases 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 () 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.

# METHODOLOGY

The procedure of this study involves experimental determination of drying shrinkage of five types of concrete that incorporates iron ore tailings as partial replacement for sand in concrete. The drying shrinkage of these concrete were compared with that of the control normal weight concrete. In order to validate the outcome of the experiments, the ultimate drying shrinkage strains were compared with a model recommended by design code, the American Concrete Institute ACI 209R-94. These shrinkage strains were further analysed using academic models developed by Bazant and Baweja B3 and GL2000.

## 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 drying shrinkage. For each type of concrete sample, the average of four concrete prisms results were used for the determination of the drying shrinkage.

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.

Strain =  (2.1)

## 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).

Where,

Esh (t, tc) = Shrinkage strain

t = Age of concrete (days)

tc = Age of concrete at the end of curing (days)

f and α = Time-ratio constants

Eshu  = Ultimate shrinkage strain

## BazanT-baweja B3 MODEL

The B3 model is considered to be more theoretically justified compared to the other models. The model 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).

(2.3)

Where,

Esh (t, tc) = Mean shrinkage strain

t = Age of concrete (days)

tc = Age of concrete at start of drying (days)

Esh∞  = Ultimate shrinkage strain

Kh = Humidity dependence factor

S(t - tc) = Time curve

Equation (2.4) expresses the ultimate shrinkage Esh∞,

(2.4)

Where,

Es∞ =

w = Water content (kg/m3)

*fcm28* = 28 days mean compressive strength (MPa)

= Constant related to cement type

= Constant related to curing condition

= Time dependence factor of shrinkage

This is further defined by (2.5).

= (2.5)

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

(2.6)

Where,

= Shrinkage half-time in days

(2.7)

ks  = Cross section shape correction factor

= Volume-surface ratio (mm)

## 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, modulus of elasticity, relative humity and volume-surface ratio. Equation (2.8) depicts the shrinkage strain Esh (t, tc) of concrete as developed by the model.

(2.8)

Where,

*t* = Age of concrete

*tc* = Age at start of drying (days)

*Eshu*  = Ultimate shrinkage strain

*β(h)* = Correction for humidity effect

*β(t - tc)*  = Correction for drying period

The ultimate shrinkage *Eshu* is expressed by (2.9),

(2.9)

Where,

*k* = Shrinkage constant for type of cement

*fcm28* = Mean compressive strength of concrete

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

(2.10)

Time function for shrinkage β (t - tc) is expressed by (2.11),

Where,

*v/s* = Volume-surface ratio

# RESULTS AND DISCUSSION

All Figures and Tables inserted should be properly referenced in the discussion of the results. Results and discussion entails the use of words to describe the implication of the results expected/obtained. Often, Figures, Tables and Plates are powerful means for proper technical result reporting and discussion. Examples of Figures and Tables are given in Figure1 and Table1.

TABLE 1: ParameterS of the Design

| Parameter | Description | Value |
| --- | --- | --- |
|  | Constant related to the flow rate into the tank | 3.3 |
|  | The cross sectional area of tank one outlet hole | 0.1781 |
|  | The cross sectional area of tank two outlet hole | 0.1781 |
| g | GraviAty constant | 981 cm/ |

## Equations

Use either the Microsoft Equation Editor or the *MathType* add-on (http://www.mathtype.com) for typing equations in your paper. Number your equations consecutively using Equation numbers in parentheses flush with the right margin, as in (1). Punctuate Equations with commas or periods when they are part of a sentence. Be sure that the symbols in your Equation have been defined before or immediately following the Equation. Use “(1)”, not “Eq. (1)” or “Equation (1)”, except at the beginning of a sentence: “Equation (1) is

(1)

## Tabulation

Use 8 pts font size Times New Roman for contents of table (see Table 1). Specify unit of measurement of table content appropriately. Use either SI (MKS) or CGS as primary units. (SI units are encouraged.). Avoid combining SI and CGS units.

# CONCLUSION

A conclusion should review the main points of the paper and should state concisely the most important propositions of the piaper. It should state the author’s views of the practical implications of the results.in addition to the deductions that can be made from the results. Do not replicate the abstract as the conclusion. A conclusion might also elaborate on the importance of the work or suggest applications and extensions.

### ACKNOWLEDGEMENTS

A short acknowledgement section can be written between the conclusion and the references. Authors may wish to acknowledge the sponsors of the research and others in brief. Acknowledging the contributions of other colleagues who are not included in the authorship of this paper is also added in this section. If no acknowledgement is necessary, this section should not appear in the paper.

# REFERENCES

**Examples for Reference citations in text**

Use the APA 6th Edition Style of referencing. The template will require the use of Author and Year Style.

1. **Indirect Quotation with Parenthetical Citation**

Libraries historically highly value intellectual freedom and patron confidentiality (LaRue, 2007).

1. **Indirect Quotation with Author as Part of the Narrative**

LaRue (2007) identified intellectual freedom and patron confidentiality as two key values held historically by libraries.

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Darwin used the metaphor of the tree of life "to express the other form of interconnectedness–genealogical rather than ecological"

(Gould & Brown, 1991, p. 14).

1. **Direct Quotation with Author as Part of the Narrative**

Gould and Brown (1991) explained that Darwin used the metaphor of the tree of life "to express the other form of interconnectedness–genealogical rather than ecological”(p. 14).

**Examples for References Page**

1. **Journals:**

Williams, J. H. (2008). Employee engagement: Improving

participation in safety. *Professional Safety, 53(12)*,

40-45.

Dauda, S. M., Ahmad, D., Khalina, A., & Jamarei, O.

(2015). Effect of cutting speed on cutting torque and cutting power of varying Kenaf-Stem diameters at different moisture contents. *Pertanika J. Trop. Agric. Sci, 38*(4), 549-561.

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Other winning equations. Newsweek, 145(20), 58-59.

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Generic Prozac debuts. (2001, August 3). The Washington

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