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A creep prediction model for concrete made from pit sand with low silica content

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Abstract

Pit sand generally has a lower silica content than sand sourced from rivers or crushed stones. The effect of this sand on the creep of concrete has not yet been fully studied. Understanding the creep on concrete can help to estimate the behaviour of structures in the future. This study aims to investigate the effect of the properties of pit sand with different chemical compositions and grain size distributions on the creep of concrete, and to develop a creep prediction model for concrete made of pit sand with low silica content. This investigation employs laboratory testing to obtain the physical and chemical properties of the sand, as well as its relationship to shrinkage and creep of concrete. The results indicate that shrinkage in concrete is influenced by the water absorption of sand. It is also found that sand with a large Calcium Oxide (CaO) compound has a smaller shrinkage compared to those with small CaO content. This study shows that sand with a high percentage of fine grains and mud content exhibit a higher creep. A concrete creep prediction model is proposed based on the modification of the B3 Model. Modifications are made by proposing a material constant obtained from short creep tests. The creep parameter obtained from the test can be better used to predict the creep of concrete.

Keywords

Pit sand, concrete, creep, model

1 INTRODUCTION

The development of infrastructures often requires local construction materials to reduce construction costs. One of the local materials frequently used in construction is pit sand from nearby sources. However, pit sand is still rarely used as a building material although it is widely distributed around the world. Pit sand generally comes from sedimentary materials and weathered rocks which form the earth's surface layer. The characteristics and properties of pit sand are highly dependent on the chemical composition of its constituents. In some cases, this type of sand has a lower silica content than sand sourced from rivers or crushed stones.

The quality of concrete is often specified by its compressive strength ($f_{\text{c}}'$). This strength represents its capability to resist a short duration of compressive loading. However, in many cases structures must withstand long duration loading or even sustained loading. In this condition, the creep and shrinkage properties of the concrete will determine the performance of the structure (Brooks & Megat Johari, 2001; Parsekian et al., 2005).

This study aims at investigating the effect of the properties of pit sand with different chemical compositions and grain distributions on the creep of concrete. A concrete creep prediction model is proposed based on the results of this study.

2 EXPERIMENTAL PROGRAMMES

2.1 Material

This research investigates pit sand taken from Merauke Regency in Indonesia, which is geographically located in the far south of Papua Province, on the border area with Papua New Guinea. Concrete in Merauke Regency is normally made from sand brought from other islands which increases the cost of infrastructures in Merauke. In this study, pit sand was taken from three local sources in Merauke Regency, namely Tanah Miring, Malind and Kurik Districts.

2.2 Material properties

The properties of Pit sand from Merauke were examined to study the effect of its properties on the resulting concrete. The physical properties of pit sand studied in this research were grain size distribution, fineness modulus, bulk density, specific gravity, water absorption, and also mud and organic content. The chemical composition of pit sand was examined using the X-ray fluorescence (XRF) method.

The material properties of Merauke Pit sand are shown in Table 1. It can be seen that sand from Malind and Tanah Miring districts have higher fineness modulus compared to sand from Kurik district, meaning that Malind and Tanah Miring sands tend to have a larger grain size. Sand with coarse gradations tends to have higher porosity
due to the lack of finer materials to fill the gaps between the larger grains. However, the sand from the three locations still meets the requirements for grain gradation of sand.

Table 1 shows the specific gravity values of the pit sand varying from 2.52 to 2.96, with the highest specific gravity from Kurik district sand. The percentage of fine grains, that is sand with a grain size less than 75 μm (passed through the No. 200 sieve) ranges from 0.35% to 3.44%, whereas the mud content ranged from 3.13% to 4.9%. Sand from the Tanah Miring area showed a higher percentage of fine grains and a higher percentage of mud content than sand taken from other locations. However, the percentage of mud content is still below the requirements specified in the code (ASTM C33–03, 2001).

| Properties                              | Unit | Kurik sand (KS) | Malind sand (MS) | Tanah Miring sand (TS) |
|-----------------------------------------|------|----------------|------------------|------------------------|
| Fineness modulus of grain size          |      | 3.594          | 3.645            | 3.644                  |
| Specific gravity                        |      | 2.96           | 2.52             | 2.69                   |
| Water absorption                        | %    | 2.60           | 2.43             | 3.19                   |
| Percentage of fine grains               | %    | 0.64           | 0.35             | 3.44                   |
| Percentage of mud                       | %    | 3.13           | 4.58             | 4.90                   |

The major chemical compounds found in the pit sand are shown in Table 2. The results show that silica oxide (SiO$_2$), iron oxide (Fe$_2$O$_3$), calcium oxide (CaO), and alumina oxide (Al$_2$O$_3$) are four major chemical compounds found in the sand. Table 2 shows that pit sand from the three sources has a smaller percentage of silica compared to sand normally used in building construction (Hasdemir et al., 2016). The largest percentage of silica oxide was only 52.2% which was found in Tanah Miring sand. This investigation also shows that pit sand from the three sources contains a large percentage of iron oxide, of which the combination of silica oxide and iron oxide makes 75.5% - 93.4% of the chemical compounds in Merauke pit sand. Also, sand from Malind district had the highest CaO content compared to those from other locations. The CaO compounds are one of the main components of cement. Hence, they need attention in their use as they can affect the properties of the resulting concrete.

| Properties                              | Unit | Kurik sand (KS) | Malind sand (MS) | Tanah Miring sand (TS) |
|-----------------------------------------|------|----------------|------------------|------------------------|
| Silica Oxide - SiO$_2$                  | %    | 28.70          | 37.30            | 52.20                  |
| Iron (III) Oxide – Fe$_2$O$_3$          | %    | 64.70          | 38.20            | 34.80                  |
| Calcium Oxide - CaO                     | %    | 0.26           | 13.40            | 0.14                   |
| Alumina Oxide – Al$_2$O$_3$             | %    | 4.75           | 1.97             | 8.90                   |
| Other compounds                         | %    | 1.59           | 9.13             | 3.96                   |

Mortar specimens had a constant weight ratio of cement to sand of 0.5, and a cement water factor of 0.4 for each mixture. There was a total of 27 mortar specimens for compressive strength and water absorption tests. All mortar specimens were cubes of size 50 mm x 50 mm x 50 mm. The test results in Table 3 show the variation of the compressive strength of the mortar ranging from 24.70 MPa to 40.68 MPa, and the water absorption of the three types of sand is small, below 2.5% in the first 10 minutes, and below 6% in 24 hours.

Results from the material test show that the sand sourced from the three locations meets the requirements for use in structural concrete. Hence, pit sand from the three locations can be used to make concrete specimens for further tests.

| Properties                              | Unit | Kurik sand (KS) | Malind sand (MS) | Tanah Miring sand (TS) |
|-----------------------------------------|------|----------------|------------------|------------------------|
| Compressive strength of cement mortar   | MPa  | 40.68          | 38.41            | 24.70                  |
10 minutes water absorption % 0.37 0.35 0.42
24 hours water absorption % 1.90 1.73 2.06

2.3 Concrete mix proportion

The concrete specimens were designed to have a compressive strength of 30 MPa with a water-cement factor of 0.4. The amount of cement was taken as a constant of 500 kg/m³ for all specimens to simulate maximum creep in concrete. The amount of water was 200 kg/m³ calculated based on the designed water-cement factor of 0.4.

Concrete specimens were made from pit sand from the three locations, namely Kurik, Malind and Tanah Miring districts in Merauke Regency of Indonesia. The composition of the concrete mixture is shown in Table 4.

Table 4 Mix proportion of concrete and number of specimens.

| Properties                  | Unit   | Kurik Concrete (BK) | Malind Concrete (BM) | Malind Concrete (BM) |
|-----------------------------|--------|---------------------|----------------------|----------------------|
| Portland cement             | Kg/m³  | 500.0               | 500.0                | 500.0                |
| Sand                        | Kg/m³  | 679.3               | 671.5                | 676.7                |
| Coarse aggregate            | Kg/m³  | 1016.9              | 1016.9               | 1016.9               |
| Water                       | Kg/m³  | 200.0               | 200.0                | 200.0                |
| w/c                         | -      | 0.4                 | 0.4                  | 0.4                  |
| Number of Specimens for Compressive Strength and Modulus of Elasticity Test | Specimens | 3                   | 3                    | 3                    |
| Number of Specimens for Creep Test | Specimens | 3                   | 3                    | 3                    |
| Number of Specimens for Shrinkage Test | Specimens | 3                   | 3                    | 3                    |

2.4 Preparation of specimens

The concrete specimens were prepared for four types of tests, namely the modulus of elasticity, compressive strength, shrinkage, and creep of concrete. Each type of test was carried out on concrete made of sand from the three locations. All test specimens were cylindrical with a diameter of 150 mm and a height of 300 mm. All specimens underwent the same treatment, such as moist curing and were stored in room conditions at the same temperature and relative humidity (ACI 209.2R-08, 2008; ASTM C512/C512M, 2010).

2.5 Testing equipment

The compressive strength and modulus of elasticity tests were conducted using a universal testing machine (UTM) equipped with a load cell to read the load. Concrete strain was measured using a strain gauge mounted on the surface of the concrete cylinder. The focus of this test was to obtain the maximum load, and the stress-strain relationship up to the maximum load for determining the modulus of elasticity of the concrete. The test setup is as shown in Fig 1.

Shrinkage tests were carried out to calculate the effect of shrinkage on the calculation of creep deformation. The shrinkage tests were carried out by installing dial gauges on the top side of the cylinders as shown in Fig 2. The shrinkage tests were conducted on three specimens for each type of concrete.

Fig. 1 Test set up for compressive strength and elasticity modulus

Fig. 2 Device used to observe the shrinkage deformation of concrete
The creep test was carried out by applying a constant load of 25% of the maximum load that can be carried by the concrete cylinder based on the compressive strength of concrete. The loading mechanism was carried out through fixed loading with steel ballast to ensure the load did not change during the test as shown in Figs 3 and 4. Deformation measurements were carried out simultaneously on three concrete specimens made from the same sand. The specimens were arranged in series to ensure that they received the same load as shown in Fig 4. The creep deformation was the average value of the measurements from the three specimens (ASTM C512/C512M, 2010).
3 RESULTS AND DISCUSSION

3.1 Compressive strength of concrete

The compressive strength and the elasticity modulus of concrete were obtained by pressing the specimens until the maximum load was reached. The stress-strain relationship of concrete up to the maximum load is shown in Fig 5. The elasticity modulus of concrete is taken as the slope of the line up to 40% of the maximum stress. Specimens BK and BM have a similar stiffness as shown in Fig 5 and the value of elasticity modulus in Table 5, whereas specimen BT exhibits much lower elasticity modulus.

The compressive strength of concrete for each type of concrete and the value of its modulus of elasticity are presented in Table 5. The compressive strength of the concrete is comparable to the compressive strength of the mortar in the material test shown in Table 3. Mortar with higher compressive strength will provide a high compressive strength of concrete, and vice versa. The compressive strength of specimen BT which was made from Tanah Miring sand was the lowest amongst the specimens. The lowest elasticity modulus and compressive strength of Tanah Miring concrete are because of the high percentage of fine grains and mud content found in the sand (Zhang et al., 2006) (Yilmaz & Turul, 2012).

| Concrete Specimens | Compressive Strength (MPa) | Elasticity Modulus (MPa) |
|--------------------|---------------------------|-------------------------|
| BK                 | 34.5                      | 25357                   |
| BM                 | 31.3                      | 22210                   |
| BT                 | 15.3                      | 13377                   |

Fig. 5 Stress-strain relationship of concrete

3.2 Shrinkage on concrete

The measurements of shrinkage deformation on concrete were carried out simultaneously with the creep deformation. The shrinkage strains were calculated by dividing shrinkage deformation with the initial length, and the measurements were carried out for 364 days. The shrinkage strain graph over time is presented in Fig 6, which shows that Tanah Miring concrete has the largest shrinkage strain when compared to the shrinkage strain of other concrete specimens in this study. The water absorption test data (Table 1) shows that Tanah Miring sand has the largest water absorption, followed by Kurik sand and Malind sand. It can be seen that the water absorption of sand is correlated with shrinkage deformation. Concrete made from sand with high water absorption has a high shrinkage value. On the other hand, concrete made of sand with low water absorption has a small shrinkage value (Yilmaz & Turul, 2012).

Results from X-ray fluorescence (XRF) tests show that sand from Malind district contains more CaO than other sand as shown in Table 2. It is known that the amount of water used in the hydration process is not as much as the amount of water given in the mix design. The unused amount of water in hydration will evaporate and cause drying shrinkage (Boyd & Skalny, 2007; Gedam et al., 2016; Irfan-ul-Hassan et al., 2017). As CaO reacts with water, sand that contains more CaO requires more water and the amount of remaining water becomes less. Hence, the shrinkage of concrete made from sand with high CaO content is smaller than those of other specimens.
Fig. 6 Development of shrinkage strains for 364 days

Fig. 6 shows that the shrinkage strain after the age of 300 days tends to be flat, which indicates a relatively small increase in shrinkage strain after that time. Fig 6 also shows that the shrinkage strain of concrete at the initial age is the highest. The shrinkage strain value at the initial age of about 28 days greatly affects the overall shrinkage strain because it contributes to about half of the final shrinkage strain value. The 28-day Fig is important because it can be used to carry out tests in a relatively shorter time and the result can be used to make estimates on the final shrinkage strain.

3.3 Creep on concrete

Creep cannot be measured directly but can be determined by subtracting the total strain with the elastic strain and shrinkage strain as shown in Equation (1) (ACI 209.2R-08, 2008; ASTM C512/C512M, 2010). The readings of strain on the creep test are recorded two to six hours after the loading start, every day for a week, every week for a month, and every month for up to a year (ASTM C512/C512M, 2010).

\[
\varepsilon_{cc} = \varepsilon_t - \varepsilon_e - \varepsilon_s
\]

(1)

where \(\varepsilon_{cc}\) is creep strain; \(\varepsilon_t\) is total strain; \(\varepsilon_e\) is elastic strain; and \(\varepsilon_s\) is shrinkage strain.

The total strain \(\varepsilon_t\) is calculated using the following equation:

\[
\varepsilon_t = \frac{\Delta L_{rt}}{L_{0rt}}
\]

(2)

where \(\Delta L_{rt}\) is length changes measured by dial gauges; and \(L_{0rt}\) is initial length.

The measurement of total strain (\(\varepsilon_t\)) for 364 days is shown in Fig 7. It shows that Tanah Miring concrete (BT) has the highest total strain, followed by Kurik concrete (BK) and Malind concrete (BM). The creep strain (\(\varepsilon_{cc}\)) can be calculated using Equation (2) after the total strain (\(\varepsilon_t\)) and shrinkage strain (\(\varepsilon_s\)) are obtained from the measurements.

Fig. 7 Total strain after sustained loading for 364 days
Creep is a long-term strain at a constant stress condition which is dependent on time and will result in an additional strain to the elastic strain of concrete (ACI 209.2R-08, 2008). Creep can be estimated using a creep coefficient $\phi_{cc}(t)$ as shown in Equation (3). The creep coefficients obtained from this research are shown in Fig 8.

$$\varepsilon_{cc,t} = \phi_{cc}(t) \varepsilon_e$$  \hspace{1cm} (3)

Creep measurement for 364 days after loading showed that the creep on Tanah Miring concrete (BT) specimen was higher than that on Malind concrete (BM) and Kurik concrete (BK). This result confirms the effect of elasticity modulus on the creep of concrete, in which concrete with low elastic modulus has a higher creep strain (Harinadha Reddy & Ramaswamy, 2018). This phenomenon is also seen in Malind concrete and Kurik concrete, where Malind concrete that has a smaller modulus of elasticity exhibits a higher creep coefficient than Kurik concrete.

Results from the physical testing (Table 1) show that Tanah Miring sand has a percentage of fine grains of 3.4%, which is far larger than that in other sands which ranges from 0.3% to 0.6%. It is known that a large number of fine grains can increase concrete creep. In addition, Table 1 shows that Kurik concrete has the lowest mud content which contributes positively to preventing high creep.

Figs 6 and 8 show a similar trend between the shrinkage graph and the creep graph. The similarity between the two graphs confirms the strong relationship between concrete shrinkage and creep (Acker & Ulm, 2001; Havlášek et al., 2021). It is also seen in Fig 8 that the creep coefficient increases rapidly at an early age. However, the creep coefficient is relatively constant without any large increase in strain after the loading duration reaches 300 days. The rapid creep strain at an early age gives the potential for creep testing in a shorter time and then creep predictions can be calculated based on the results of the measurement. The definition of early age is relative, but it can be taken to be approximately 28 days as shown by a dashed line in Fig 8 which indicates a reasonable estimate.

### 3.4 CREEP PREDICTION MODEL IN CONCRETE

Creep prediction in concrete has been studied for decades (Bazant, 1977; Bažant, 2001; Bazant & Baweja, 2000; Harinadha Reddy & Ramaswamy, 2018; Nakov et al., 2018; Song, H.W., Song, Y.C., Byun, K.J., Kim, 2001; Torres et al., 2021). Creep prediction models have even been included in codes of practice (ACI 209.2R-08, 2008; Torres et al., 2021). However, the existing models cannot be applied to materials in all areas. Concrete made from Merauke sand which has low silica and high iron oxide content cannot be well predicted by available creep models. The existing creep prediction models show large discrepancies when they are applied to concrete specimens in this study. Hence, a modification to existing models is needed for predicting creep of concrete made from Merauke sand.

One of the complete creep models is the B3 Model (Bažant, 2001; Bazant & Baweja, 2000). This model has taken into consideration many aspects to estimate creep in concrete, including water-cement ratio, cement content, the ratio of aggregate to cement, compressive strength and elasticity modulus of concrete, concrete age and duration of loading, concrete stress during loading, shape and surface area of concrete, and relative humidity. Other aspects are calculated using the main data. Although the B3 Model has not been able to accurately model the creep in Merauke concrete, this model is flexible enough to be modified based on the behaviour of the existing
concrete specimens. Hence, a modification of the B3 Model was carried out for estimating creep in Merauke concrete. The Bazant-Baweja B3 Model uses a compliance function to reduce the risk of error due to an inaccurate modulus of elasticity. This model separates the basic creep and drying shrinkage. The compliance function $J(t, t_0)$ is calculated according to the following steps:

Prediction of instantaneous compliance $q_1$ based on the compressive strength and modulus of elasticity of concrete, which is calculated by Equations (4) to (6) as follows:

$$ f_{cm28} = f_c + 8.3 \text{MPa} $$

$$ E_{cm28} = 4734 \sqrt{f_{cm28}} $$

$$ q_1 = 1/E_0 = 0.6/E_{cm28} $$

Where $f_c$ is the compressive strength of concrete; $f_{cm28}$ is the mean of 28-day strength; and $E_{cm28}$ is the mean of the 28-day elastic modulus.

Afterwards, the prediction of compliance function for basic creep $C_0(t, t_0)$ is calculated using Equations (7) to (15) as follows:

$$ q_2 = 185.4 \times 10^{-6} \cdot c^{0.5} \cdot f_{cm28}^{-0.9} $$

$$ Q_f(t_0) = [0.086 (t_0)^{2/9} + 1.21(t_0)^{4/9}]^{-1} $$

$$ r(t_0) = 1.7(t_0)^{0.12} + 8 $$

$$ Z(t, t_0) = (t_0)^{-m} \cdot \ln[1 + (t - t_0)^n] $$

$$ Q(t, t_0) = Q_f(t_0) \left[ 1 + \left( \frac{Q_f(t_0)}{Z(t, t_0)} \right)^{r(t_0)} \right]^{-\frac{1}{r(t_0)}} $$

$$ q_3 = 0.29 \left(\frac{w}{c}\right)^4 \cdot q_2 $$

$$ q_3 \cdot \ln[1 + (t - t_0)^n] $$

$$ q_4 = 20.3 \times 10^{-6} \cdot \left(\frac{a}{c}\right)^{-0.7} $$

$$ C_0(t, t_0) = q_2 \cdot Q(t, t_0) + q_3 \cdot \ln[1 + (t - t_0)^n] + q_4 \cdot \ln\left(\frac{t}{t_0}\right) $$

where $c$ is cement content (kg/m3); $t_0$ is specimen age at the beginning of loading; $m$ and $n$ are empirical parameters which can be taken the same for all specimen (normal $m = 0.5$ dan $n = 0.1$); $w/c$ is water cement content; and $a/c$ is aggregate to cement ratio.

The next step is to calculate the compliance function for drying creep $C_d(t, t_0, t_c)$ using Equations (16) to (26) as follows:

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

$$ \varepsilon_{s\infty} = -\alpha_1 \alpha_2 \left[ 0.019w^{2.1} f_{cm28}^{-0.29} + 270 \right] \times 10^{-6} $$

$$ E_{cm607}/E_{cm(t_c+\tau_{sh})} = 1.0805/[(t_c + \tau_{sh})/4 + 0.85(t_c + \tau_{sh})]^{0.5} $$

$$ \varepsilon_{sh\infty} = -\varepsilon_{s\infty} \frac{E_{cm607}}{E_{cm(t_c+\tau_{sh})}} $$

$$ q_5 = 0.757 \cdot f_{cm28}^{-1} \varepsilon_{sh\infty} \cdot 10^6 $$

$$ S(t_0 - t_c) = \tanh\left[\left( t_0 - t_c \right)/\tau_{sh}\right]^{0.5} $$

$$ H(t_0) = 1 - (1 - H)S(t_0 - t_c) $$

$$ S(t - t_c) = \tanh\left[\left( t - t_c \right)/\tau_{sh}\right]^{0.5} $$

$$ H(t) = 1 - (1 - H)S(t - t_c) $$

$$ f(H) = [\exp(-8H(t)) - \exp(-8H(t_0))]^{0.5} $$

$$ C_d(t, t_0, t_c) = q_5 \cdot [\exp(-8H(t)) - \exp(8H(t_0))]^{0.5} $$

where $t_c$ is curing time; $k_s$ is cross-section shape correction factor for B3 Model(ACI 209.2R-08, 2008; Bazant & Baweja, 2000); $V/S$ is volume to surface ratio; $\alpha_1$ is a constant of cement type in B3 Model; $\alpha_2$ is constant of curing condition in B3 Model; $w$ is water amount in kg/m3; and $h$ is average relative humidity.
Next, compliance function $J(t, t_0)$ is calculated using Equation (27). Creep coefficient $\Phi(t, t_0)$ and creep strain $\varepsilon_c(t, t_0)$ can then be calculated accordingly using Equations (28) and (29).

$$J(t, t_0) = q_1 + C_0(t, t_0) + C_d(t, t_0, t_c)$$  \hspace{1cm} (27)

$$\Phi(t, t_0) = E(t_0) \cdot J(t, t_0) - 1$$  \hspace{1cm} (28)

$$\varepsilon_c(t, t_0) = J(t, t_0) \cdot \sigma$$  \hspace{1cm} (29)

### 3.5 Modification of creep model

In this study, the B3 Creep Model is modified to account for the different properties of sand. One important parameter in the B3 Model is the shrinkage half-time ($\tau_{sh}$) in Equation (16). This parameter is modified based on the results of creep measurements at a short duration. The results of this study show that the creep coefficient increases rapidly at an early age up to about 28 days as shown in Figure 8. Hence, the creep parameter of shrinkage half-time ($\tau_{sh}$) is studied at 28 days of loading. To take into account the variation in measurement results, the calculation is carried out at the age of 27, 28, and 29 days and then the average is taken.

The procedure for modifying the B3 Model based on the results of the creep test is as follows:

- calculate compliance function $J(t, t_0)$ based on the creep coefficient value $\Phi(t, t_0)$ from the measurement results using the relationship in Equation (27).
- calculate the instantaneous compliance $q_1$ using Equation (6).
- calculate compliance function for basic creep $C_0(t, t_0)$ using Equations (7)–(15).
- calculate compliance function for drying creep $C_d(t, t_0, t_c)$ based on the values of $J(t, t_0)$, $q_1$, and $C_0(t, t_0)$ using Equation (26).
- calculate the value of shrinkage half-time ($\tau_{sh}$) that meets the value of $C_d(t, t_0, t_c)$ based on Equations (21)–(26).

Figure 9 shows the value of compliance function $J(t, t_0)$, at the age of 27 to 29 days from concrete made from three types of local sand in Merauke. Tanah Miring concrete (BT) shows a higher compliance function $J(t, t_0)$ value compared to other specimens. The value of compliance function $J(t, t_0)$ is then used to calculate the value of compliance function for drying creep $C_d(t, t_0, t_c)$ as shown in Figure 10. It shows that the Compliance function for drying creep $C_d(t, t_0, t_c)$ of Malind concrete (BM) is higher than that of other specimens.

The calculated values of shrinkage half-time ($\tau_{sh}$) are presented in Figure 11 which shows the variation of shrinkage half-time ($\tau_{sh}$) for each specimen. The shrinkage half-time ($\tau_{sh}$) in Table 6 was calculated from the average value of shrinkage half-time ($\tau_{sh}$) for each concrete. In this modification, the estimation of shrinkage half-time ($\tau_{sh}$) in Equation (16) is expanded to Equation (30) by including the constant $K_{hs}$ as a material property. The value of $K_{hs}$ can be calculated using the average shrinkage half-time ($\tau_{sh}$) value in Table 6, and the results are written in Table 6.

![Fig. 9 Compliance function $J(t, t_0)$ at age 27 to 29 days of loading](image-url)
\[ \tau_{sh} = K_{hs} t_c^{-0.08} f_{cm28}^{-0.25} [2k_s(V/S)]^2 \quad (30) \]

| Concrete specimens          | Average shrinkage half-time (\(\tau_{sh}\)) | Coefficient Khs |
|-----------------------------|---------------------------------------------|-----------------|
| Kurik concrete (BK)         | 36.15                                       | 0.0089          |
| Malind concrete (BM)        | 23.33                                       | 0.0056          |
| Tanah Miring concrete (BT)  | 92.67                                       | 0.0195          |

### 3.6 Model verification

Equation (30) and Table 6 are employed to replace Equation (16) as the modifications of the B3 Model to predict concrete creep. The creep prediction of Merauke concrete and the creep test data up to 364 days are presented in Figures 12-14. It can be seen that the Modified B3 Model can estimate the actual creep data better than the original B3 Model. However, the difference between models and creep data in BT specimens is still obvious. Figure 11 shows that the variation of shrinkage half-time (\(\tau_{sh}\)) values in specimens BT on days 27 to 29 are larger than those in other specimens. Better estimates of creep can be obtained when the half shrinkage constant (\(K_{hs}\)) is calculated from a small variation of shrinkage half-time (\(\tau_{sh}\)) values as shown in specimens BK and BM.
CONCLUSION

Shrinkage in concrete is influenced by the physical and chemical properties of the constituent materials. Concrete made from sand with high water absorption has a greater shrinkage value than concrete made from sand...
with low water absorption. Furthermore, sand with a high CaO content is found to produce concrete with a lower shrinkage value.

Creep in concrete is influenced by the physical properties of sand, where sand with a high percentage of fine grains exhibits a larger creep. In addition, the mud content also affects creep in concrete. The results of compressive strength and modulus of elasticity of concrete show that concrete with high compressive strength and high modulus of elasticity tends to have smaller creep.

A concrete creep prediction model has been developed based on B3 Creep Model for estimating creep on concrete made from pit sand. The modification is conducted by proposing a half shrinkage constant $K_{sh}$ as a material property. This constant can be obtained from short-duration creep tests. The creep parameters obtained from this test can be used to predict concrete creep better.

Compliance with ethical standards
Conflict of interest. On behalf of all authors, the corresponding author states that there is no conflict of interest.

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