Correlation between results of constant voltage RCM test and those of variable voltage RCM test

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Abstract. Laboratory tests were performed on 74 sets of concrete specimens with the constant voltage RCM test and variable voltage RCM, respectively. Based on the regression analysis method, a computational model for transformation relation between test results of constant voltage RCM and those of variable voltage RCM was developed. The accuracy and applicability of the proposed model were validated by the tested data and existing model. Results show that the proposed model is applicable with higher accuracy.

1. Introduction
 Chloride diffusion coefficient the most important design parameter for durability design of concrete structures[1,2]. RCM test method has become the most popular testing method of chloride diffusion coefficient, due to it has the advantages of short test cycle and user-friendly control[3].

According to the different mode of power on voltage, RCM test method can be divided into constant voltage test method and variable voltage test method[4,5]. For constant voltage RCM, the voltage is constant at 30V. For variable voltage RCM, the voltage range is 15V to 60V. Previous research has shown that the test result of constant voltage RCM is different from the result of variable voltage RCM. In order to achieve the standardization of RCM test results, it is necessary to study the relation between test results of constant voltage RCM test and variable voltage.

In this paper, based on the RCM test data, a model for transformation relation between test results of constant voltage RCM test and test results of variable voltage RCM was developed by regression analysis method. The accuracy and applicability of the proposed model were validated by current model.

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2. Experimental program

2.1. Materials
 The cement used was Type I Portland cement provided by Huarun Cement (Nanning) Co. Ltd. Mineral admixtures including class F fly ash and grade 100 SG were used for replacement of Portland cement. The chemical compositions of the cement are shown in Table1. The chemical properties of cement, fly ash and SG are shown in Table 1. The coarse aggregate used in this study is crushed...
limestone with the size of 5-20 mm and the apparent density of 2590 kg/m$^3$. The fine aggregate used is river sand with fineness modulus of 2.7 and the apparent density of 2560 kg/m$^3$. A polycarboxylate superplasticizer is used and its water reduction rate is 20%.

Table 1. Chemical compositions of binder.

| Binder | SiO$_2$ | Al$_2$O$_3$ | Fe$_2$O$_3$ | CaO | MgO | SO$_3$ | Cl$^{-}$ | f-CaO | SiO$_2$ |
|--------|---------|-------------|-------------|------|-----|--------|---------|-------|--------|
| Cement | 19.17   | 5.90        | 4.17        | 63.59| 1.08| 2.11   | 0.009   | 0.94  | 19.17  |
| FA     | 46.87   | 37.39       | 4.61        | 4.44 | 1.23| 0.59   | 0.009   | 0.24  | 46.87  |
| SG     | 33.75   | 15.76       | 1.43        | 36.81| 10.82| 0.03   | 0.038   | 0.18  | 33.75  |

2.2. Specimens and tested programs

A total of 74 mixes were tested, as listed in Table 2. The water-to-binder ratio range is from 0.3 to 0.5. The replacement of fly ash range is from 0 to 0.75. The replacement of GGBFS range is from 0 to 0.75. The concrete cylinder specimens with the size of Φ100×200 mm were demolded 24 hours after casting, then cured in a standard curing room for 21 days. Each specimen was cut into three test specimens with a concrete saw. The size of each test specimen is Φ100×50 mm. After cutting, the test specimens cured for another 7 days. Constant voltage RCM test is performed described in Chinese Standard GB/T 50476-2008. Variable voltage RCM test is performed described in NT Build 492.

Table 2. Concrete mix proportion.

| Range | Water-to-binder ratio | Replacement of fly ash | Replacement of GGBFS |
|-------|------------------------|-------------------------|-----------------------|
| 0.3~0.5 | 0~0.75 | 0~0.75 |

3. Results and discussion

Based on the results of constant voltage RCM and variable voltage RCM and regression analysis method[6], the models for transformation relation between test results of constant voltage RCM test and test results of variable voltage RCM were developed respectively, which consist of OPC concrete model, FA concrete model, SG concrete model and FA and SG concrete.

The OPC concrete model is as follow:

$$D_{NTB} = 0.6411D_{RCM} + 4.1272$$  \hspace{1cm} (1)

where $D_{NTB}$ is the test value of variable voltage RCM, $D_{RCM}$ is the test value of constant voltage RCM.

The FA concrete model is as follow:

$$D_{NTB} = 0.6721D_{RCM} + 2.658$$  \hspace{1cm} (2)

The SG concrete model is as follow:

$$D_{NTB} = 0.612D_{RCM} + 3.6511$$  \hspace{1cm} (3)

The FA&SG concrete model is as follow:

$$D_{NTB} = 0.637D_{RCM} + 3.6187$$  \hspace{1cm} (4)

The prediction effect of the above models are shown in Fig. 1.
Figure 1. Prediction effect of different transformation relationship models.

From Fig. 1, there were no obvious differences among the calculation results of OPC concrete model, FA concrete model, SG concrete model and FA&SG concrete model, which indicate that the types of concrete have no influence on the correlation between test results of constant voltage RCM test and test results of variable voltage RCM.

Therefore, based on all the tested data of constant voltage RCM and variable voltage RCM, a model for transformation relation between test results of constant voltage RCM test and test results of variable voltage RCM is developed, which is as follow:

\[ D_{NTB} = 0.5887D_{RCM} + 3.9449 \]  

The prediction effect of the above models are shown in Fig. 2.

Figure 2. The relationship between results of constant voltage RCM and variable voltage RCM.

As is shown in Fig. 2, the predicted values obtained by the proposed model are uniformly distributed on both sides of the fitted line, which indicates that the accuracy of the proposed model is satisfied. When the value of DRCM is less than 10×10^{-12}m^2/s, the predicted values obtained by the
proposed model are distributed above the equality line, which indicates that the value of variable voltage RCM is larger than the value of constant voltage RCM. When the value of DRCM is not less than \(10 \times 10^{-12} \text{m}^2/\text{s}\), the predicted values obtained by the proposed model are distributed below the equality line, which indicates that the value of variable voltage RCM is less than the value of constant voltage RCM.

Current model of the transformation relationship are selected to validate the accuracy and applicability of the proposed model. As shown in Fig. 3 and Fig. 4, the experimental data were collected to compare the accuracy and applicability between reference [7] model and proposed model.

It is clear that a large number of predicted values obtained by model [7] are located above the equality line, which indicates that predicted values are significantly larger than tested values. Furthermore, the predicted values obtained by the proposed model are not only much closer to the
equality line than those of the reference [7] model, but also are uniformly distributed on both sides of the equality line, which indicates that the accuracy of the proposed model is satisfied. The mean value for the ratio of predicted value to tested value and residual mean variance were calculated. For the reference model, the values for $\mu$ are larger than 1, and the values for $\delta$ are larger than 5, which indicates that the predicted values are far away from tested values, and the dispersal of the reference model is much larger than the proposed model. For the proposed model, the values for $\mu$ are much closer to 1, which indicates that the predicted values are much closer to tested values, and the dispersal of the proposed model is the smallest, thus demonstrating the high accuracy of the proposed model. This is because the model [7] is lack of data greater than $15\times 10^{-12}$ m$^2$/s, which decreases the prediction accuracy. Consequently, the proposed model is of higher accuracy.

4. Conclusions

Laboratory tests were performed on 74 sets of concrete specimens with the constant voltage RCM and variable voltage RCM. OPC concrete transformation relationship model, FA concrete transformation relationship model, SG concrete transformation relationship model and FA and SG concrete transformation relationship model are developed respectively. Further, based on all the tested data of constant voltage RCM and variable voltage RCM, a comprehensive transformation relationship model was developed. Following conclusions can be drawn:

- The types of concrete have no significant influence on the correlation between test results of constant voltage RCM test and test results of variable voltage RCM
- When the value of $D_{\text{RCM}}$ is less than $10\times 10^{-12}$ m$^2$/s, the value of $D_{\text{NTB}}$ is greater than the value of $D_{\text{RCM}}$. When the value of $D_{\text{RCM}}$ is not less than $10\times 10^{-12}$ m$^2$/s, the value of $D_{\text{NTB}}$ is less than the value of $D_{\text{RCM}}$.
- Comparing with the reference model, the proposed model is of higher accuracy.

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