Experimental study on autogenous volume deformation of RCC mixed with MgO

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Abstract. The application of MgO to control thermal stress for concrete structures has achieved many accomplishments over the years. MgO is an important type of materials for the shrinkage cracking control of mass concrete in general, and Roller Compacted Concrete (RCC) dams in particular. Previous studies have investigated the application of MgO concrete and have proven the cracking prevention of MgO concrete. The purpose of this paper is to measure the Autogenous Volume Deformation (AVD) of RCC mixed with the MgO-expansive agent. And these experiments were conducted under different MgO content, temperature and curing time conditions. The experimental results of the AVD process show that the AVD process increased with the MgO content, curing time and temperature condition. The research outcomes are evidence that the hydration of expanded materials in concrete can compensate for shrinkage.

1. Introduction

There are many reasons for concrete cracking, including thermal stress and shrinkage during concrete construction period[1]. Massive concrete dams suffer from the limitations of foundation and the increase of thermal hydration of cement, and due to the large concrete masses, poor internal heat transfer performance. The cracks occur when the tensile stress exceeds the maximum allowable tensile stress of the concrete. The occurrence and development of these cracks not only affect the aesthetics of the project, but also destroy the integrity of the concrete dam, change the stress state of the dam, and even result in the concentrated leakage passage of dam, which causes hidden dangers for the dam. Therefore, the control of stress and temperature in concrete is a crucial task in the construction of concrete, and gravity concrete dams. In RCC dam construction, temperature control is even more critical[2].
In order to control the temperature in concrete, some typical methods are used including using the cooling water pipe, precooling aggregate, increasing construction time, adding fly ash, and other traditional temperature control methods [3]. Although these methods contribute effectively to the control of concrete temperature in the dam, they increase construction time and cost money. Therefore, scientists have been continuously looking for new methods to prevent concrete cracks, including the addition of MgO-type expansion agents that can compensate for shrinkage of concrete and relieve the cracking risk [4]. Fact shows that MgO, after being heated at high temperatures, will naturally inflate during hydration to transform to MgOH.\textsubscript{2}, which has good latency, and a unique developmental delay by using this characteristic of MgO, the construction process of mass concrete can be effectively simplified, the concrete cracking of the dam body can be avoided, the construction progress can be accelerated, and the engineering investment can be saved.

History shows the changes in the proportion of MgO in concrete content. In the 1880s, cement with 16% to 30% MgO content was used in building bridges in France[5]. In the 1970s, research results at the Liujiaxia and Hengren dams in Jilin province, China demonstrated the reason for fewness cracks, which the AVD of MgO concrete made compensation for shrinkage at a lower temperature. The autogenous deformation of the Liujiaxia dam was 60\times10^{-6} and that of the Hengren dam was 100\times10^{-6} when concrete mixed with 4.5% to 6% MgO content. Baishan Dam used 5% MgO mixed into the concrete without concrete cracks. This result is the cause of the hydration of MgO cement [6]. Therefore it can be asserted that the use of MgO in concrete is an important scientific foundation to improve the autogenous crack prevention of concrete. Previous studies as Lei Guo et al.[7], S. H.Liu et al. [8], P.W. Gao et al. [9] made predictions about the AVD process of MgO concrete. These studies and applications have shown that the expansion properties of MgO materials will determine the expandability of MgO cement. However, the quality of MgO expansion materials is closely related to production conditions, calcination systems, grinding fineness and particle size distribution, product uniformity and stability. The expansion behavior depends on many parameters including its reaction activity, dosage, mix proportion of concrete, curing temperature and age, etc.

For the reasons mentioned above, this paper studies the Autogenous volume deformation of Roller compacted concrete mixed with MgO. The experiment process under laboratory conditions took into account factors such as the content of MgO, the temperature, and the curing age. In the next sections, the experimental methods and results are first introduced, followed by the formula for calculating the AVD coefficient of RCC mixed with MgO. Finally, the visual results of the AVD process of MgO concrete will be presented with discussions.

2. The applications of MgO

According to the previous statement, traditional techniques for controlling the temperature rise of concrete have been developed relatively. Nowadays, the technology of adding magnesia concrete to construct dams and RCC arch dams which have gradually become a research hotspot. So for thermal stress and temperature control, it is necessary to study the AVD properties of RCC mixed with MgO. As of 1995, the application of MgO concrete on the whole dam had been adopting the first way, for example, the dams in Liujiaxia, Hengren, Panjiakou; all of them adopted cement which contained 2-5% MgO. Since then, the method of adding MgO into the cement in the factory or adding MgO into the concrete while mixing was adopted in the dam, such as Shitang, Tongjiezi, Shuikou, Doufeng, Yanjinqiao, Liujiaxia dam, Qingxi, and Feilaixia dams in China [6].

3. Experimental study on the expansion of RCC mixed with MgO

3.1 The experimental methods

As mentioned above, applications of using MgO to concrete have been widely used to increase the construction speed and prevent cracks of concrete dams. Besides the expansibility of MgO, the quality and duration of storage of cement, the type and content of mixtures, the manner, and content of MgO, aggregate gradation and the number of adhesives are the factors that affecting the expansibility of
MgO concrete. A large number of experimental studies and engineering applications show that the expansibility of MgO cement mainly depends on the expansibility of MgO material. However, the quality of MgO expansive material is closely related to the production conditions, calcination system, grinding fineness and particle size distribution, product uniformity and stability. In this paper, the authors focus on the experiment of the AVD process of MgO concrete under different MgO content, temperature and curing time conditions. There are three duplicate concrete specimens of size 150x150x500(mm) in each experimental group, in which the expansive material mixed with 3%, 4%, and 5% of MgO contents, respectively. And all experimental groups mixed with a fixed content of 60% Fly ash (FA) content. Although the effective content of MgO and FA will definitely affect the AVD process, however, in this article, the authors only emphasize the expansive deformation and development of the AVD process. The AVD of MgO concrete depends on the MgO content, the curing time and temperature. Therefore, the experiment of RCC mixed with MgO which were carried out by China National Standard DL/T5433-2009[10]. The material mixing proportions of experiment specimens as shown in Table 1 following. In particular, the type of MgO used has a reaction time of 120(s) and an effective MgO content greater than 90%.

| Strength grade | MgO content % | Fly ash % | W/C | The mix proportions of concrete (kg/m³) | Coarse aggregate size | MgO |
|---------------|---------------|-----------|-----|--------------------------------------|----------------------|-----|
|               |          | 0.55      |     | Cement Fly ash | Water | Sand | 40-60 mm | 20-40 mm | 5-20 mm |   |
| C9015         | 3          | 60        | 0.55| 66 99 91 | 729 | 425 | 566 | 425 | 4.8 |
|               | 4          | 60        | 0.55| 66 99 91 | 729 | 425 | 566 | 425 | 6.4 |
|               | 5          | 60        | 0.55| 66 99 91 | 729 | 425 | 566 | 425 | 7.9 |

3.2 The experimental conditions
In the experiment on the AVD process of MgO concrete, the concrete specimens were stored at 20°C for the first 2 days after casting. And specimens were stored in HBY-28B Concrete Standard Curing (CSC) box which was cured at 20°C and relative humidity above 95% for 2 days before removing the mold. This equipment was manufactured according to the China National Standard GB/T50081-2002 Standard for Test Method of Mechanical Properties on Ordinary Concrete[11], and JG238-2008 Standard Curing Chamber for Concrete[12]. This experimental tool has intelligent digital to control the temperature and humidity under standard conditions. During this period, the concrete specimens may shrink, however concrete is still relatively soft and adjustable, so the amount of shrinkage deformation will be very low. After removing the mold, the specimens will be further experimented for 207 days with HBY-28B, and under laboratory conditions. Each test group was tested at 20°C, 30°C, 40°C, and 50°C, respectively. During the 207 days of this experiment, the length of the MgO concrete specimens after expansion will be accurately measured through two Linear Variable Differential Transformers (LVDTs). The experimental setting is shown in Fig. 1 following.
According to the China National Standard DL/T5296-2013[13], for small linear expansion deformation in three-dimensional space of an isotropic material, the AVD of the MgO concrete specimen will be measured as Eq. (1) following:

\[ \varepsilon_{r} = 3 \frac{L_{r} - L_{0}}{L_{0} - 2 \cdot \Delta} \]  

Where: \( \varepsilon_{r} \) is the coefficient of volume deformation of the MgO concrete sample at \( \tau \)-days of age. 

\( L \) is the measurement length of MgO concrete which was carefully measured at each time throughout the 207-day experimental period where the time of measurements is shown in Figs. 2,3,4. \( L_{0} \) is the reference length of the test specimen which was accurately measured immediately after removing the mold, mm. \( \Delta \) is the length of the stud which was partially positioned into the specimen and be connected with LVDTs, mm. Based on the experimental procedure described above, the experimental results of the AVD process of concrete are calculated by Eq. (1) and shown in Figs. 2,3,4 following.

4. Results and discussions

According to Eq. (1) the expansion calculation results of RCC mixed with 5%, 4%, and 3% content of MgO which are calculated and shown in Figs. 2,3,4 following. As can be seen, the expansion appeared as a result of the expansion of MgO concrete.
Fig. 4. The AVD process of the specimen mixed with 3% MgO content

The maximum AVD value \( \varepsilon_{\text{max}} \) of the experimental results corresponding to each case are calculated and listed in Table 2. In this experimental, \( \varepsilon_{\tau=207\text{-day}} \) is the AVD value at the 200th experiment day.

Table 2. The values of \( \varepsilon_{\tau=207\text{-day}} \) for three experimental specimens

| MgO (%) | Specimen mixed with 5% MgO | Specimen mixed with 4% MgO | Specimen mixed with 3% MgO |
|---------|-----------------------------|-----------------------------|-----------------------------|
| Temperature (\( T/°C \)) | 20 30 40 50 | 20 30 40 50 | 20 30 40 50 |
| \( \varepsilon_{\tau=207\text{-day}} (\times10^{-6}) \) | 65 95 158 209 | 40 68 90 127 | 23 44 57 81 |

As mentioned above, during 207 days of experiments, all concrete specimens were tested with HBY-28B (CSC) box in different curing temperature 20°C, 30°C, 40°C, and 50°C, respectively. These figures show the AVD process of test samples was mixed with 5%, 4% and 3% of MgO content, respectively. The experimental results in this paper show that the AVD process of MgO concrete increased the MgO contents, the curing time and temperature increased. It proves that the shrinkage of concrete has been compensated by the hydration of the expanded materials mixed in concrete [14]. Figures 2, 3, 4 show that MgO concrete at early age tends to increase rapidly, while at later ages it tends to be constant. Specifically, the AVD process of MgO concrete increased rapidly in the first 200 days, and slower after that. These expansive deformation process can be surmised by mathematical models, from which it will be applied in the calculation of concrete dam temperature control, contributing to the crack prevention.

5. Conclusions

The expansive experimental model of RCC mixed with MgO is proposed to consider the AVD process under different MgO content, curing temperature and time conditions. This paper used three duplicate concrete specimens in each experimental group mixed with 3%, 4%, and 5% MgO, respectively. The specimens were cured at 20°C, 30°C, 40°C, and 50°C, and relative humidity above 95% under standard experimental conditions. Experimental results have demonstrated the expansion effectiveness of MgO concrete, and with the increasing of MgO-expansive agent content, curing temperature and time, the AVD of RCC increased. The results of this study will contribute to the scientific foundations in the use of MgO in general and its application in concrete crack control.

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