Influence of specimen size on autogenous volume deformation of concrete with magnesium oxide

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Abstract. In order to investigate the influence of specimen size on autogenous volume deformation of concrete with magnesium oxide (MgO), the role of autogenous volume deformation of MgO concrete was tested. The results show that the specimen size has an obvious influence on autogenous volume deformation of MgO concrete.

1. Introduction

Cracks appear in mass concrete to different extents during their life time, decreasing the crack resistance of the concrete. Some penetrating cracks may endanger the safety of a project. Mehta and Pirtz mixed MgO into concrete as an expanding agent, and they studied the expansion character of MgO, the results showed that expansion deformation generated by the hydration of MgO could compensate for temperature-induced shrinkage [1, 2]. This had also been proved by engineering practice in China [3]. There are many factors that influence autogenous volume deformation of MgO concrete. Fang studied the influence of factors such as the curing temperature of test-piece and amount of admixture of MgO on deformation characteristics of concrete [4]. Chen pointed out that fly ash leading to the autogenous volume deformation of additive MgO concrete increased in the early stages and decreased later [5]. Li pointed out that with increased water-cement ratio, the autogenous volume deformation of MgO concrete also increased [6].

However, there are no relevant studies on the influence of the size of test specimen on autogenous volume deformation of MgO concrete, let alone taking the size effect of autogenous volume deformation of MgO concrete into industrial deformation. In accordance with “Test Code for Hydraulic Concrete (SL352-2006)” [7], the standard size of test specimen for testing autogenous volume deformation of the concrete is 200mm with its diameter, and 500 mm-600 mm with its height; the aggregate whose particle size is greater than 40 mm will be filtered out when the test specimen formed (in short, standard test specimen). Obviously, there exist differences in construction. So, if it is assumed that aggregate whose particle size is greater than 40 mm is not filtered out, how does the autogenous deformation volume of MgO concrete proceed? This research tests MgO concrete samples with different sizes to measure the autogenous volume deformation and MIP of drilling core sample, aged of 1 year, for revealing the effects of specimen sizes on the autogenous volume deformation of MgO concrete.

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2. Experiment

2.1. Raw materials

- Cement: Ordinary Portland cement of Lafarge produced in Shuicheng County, Guizhou province. The density is 3.05 g·cm\(^{-3}\), specific surface area is 271 m\(^2\)·kg\(^{-1}\), water requirement of normal consistency is 26.3% and the stability is qualified, the main chemical component of the cement is shown in Table 1.

| CaO | SO\(_2\) | Al\(_2\)O\(_3\) | Fe\(_2\)O\(_3\) | MgO | SO\(_3\) | Na\(_2\)O | K\(_2\)O | Loss |
|-----|---------|---------------|---------------|-----|---------|---------|--------|------|
| 58.15 | 21.23  | 6.34         | 3.81         | 3.01 | 2.70   | 0.19   | 0.30  | 3.78 |

- Fly ash: Class F and II fly ash processed in Guizhou Yemazhai Power Plant. The water content ratio is 91.2%, the loss on ignition is 6.20%, fineness (residue on sieve filtered out by 0.045mm) is 16.55% and the density is 2.46 g·cm\(^{-3}\), which meets the requirement of “Technical specification of fly ash for use in hydraulic concrete (DL/T5050-2007)”, the testing result of its main chemical component is shown in table 2.

| SiO\(_2\) | Al\(_2\)O\(_3\) | Fe\(_2\)O\(_3\) | CaO | MgO | SO\(_3\) | Na\(_2\)O | K\(_2\)O | TiO\(_2\) | MnO | Loss |
|----------|---------------|---------------|-----|-----|---------|---------|--------|---------|-----|------|
| 45.77    | 24.72         | 12.80         | 3.86 | 2.48 | 0.60   | 0.68   | 1.31   | 2.90    | 0.08 | 6.20 |

- Magnesium oxide: The magnesium oxide is produced by Dongfang Huamei Co. Ltd, in Haicheng city, Liaoning province. The density is 3.27 g·cm\(^{-3}\), its quality is in accordance with “Quality technical requirements of light magnesia materials for water conservancy and hydropower projects (for Trial Implementation)”. The main chemical component is shown in table 3.

| MgO | SiO\(_2\) | CaO | Fe\(_2\)O\(_3\) | Al\(_2\)O\(_3\) | SO\(_3\) | Loss |
|-----|---------|-----|---------------|---------------|---------|------|
| 93.36 | 2.05 | 0.77 | 0.62         | 0.36         | 0.12   | 1.74 |

- Aggregate: The aggregate is manufactured sand and macadam in a hydropower station in Guizhou province. The fineness modulus of manufactured sand is 2.98, which belongs to class II (medium sand),and the grain composition is qualified.

- Superplasticizer: The superplasticizer is produced by Chongqing Sansheng Special Building Materials Co. Ltd; the quality conforms to the current standard.

2.2. Mixture proportion of concrete

The concrete compositions are shown in Table 4. This mixture proportion is the same raw materials, water-binder ratio is 0.55, fly ash replacement is 30%, the mixing amount of MgO is 0%, 0.6%, 8%, 10% and adjusted the mixing amount of super-plasticizer to make sure the mixture reaches the same...
slump from 20 mm to 50 mm.

2.3. Conditions and methods
Test specimens of the concrete are as follows: the standard specimen with 200 mm diameter and 500 mm height; medium specimen with 250 mm diameter and 600 mm height; and large specimen with 250 mm diameter and 600 mm height.

The test conforms with “Test Code for Hydraulic Concrete (SL352-2006)”. When the volume of molding concrete turns into the standard test specimen, the coarse aggregate whose grain diameter is greater than 40 mm has been filtered out; when it comes to mold medium test specimen and large test specimen, the coarse aggregate whose grain diameter is greater than 40 mm has not been filtered out. Before sealing the test specimen, embedding vertically differential strain gauge into the central position of specimen barrel to read data. After sealing the test specimen, it is placed in the environment of constant temperature (20±2℃) and water-proofed.

Core and samples from drilling in the test specimen of concrete after 1 year of aging, are used to test the pore structure of the concrete.

3. Results and analysis

3.1. Results
Figs 1-4 show the volume deformation of MgO concrete from the test results for the specimens of different sizes. Also, the testing results of MIP specimens are summarized in Table 5.

3.2. Analysis
- As it can be seen from figure 1, no matter what sizes of the test specimens are, the volume deformation of concrete without MgO appears contraction state. In addition, before the age of 60 days, all the curves decreased sharply; after the age of 60 days, the contraction rate of volume deformation of the concrete dropped obviously, it is namely that it is appeared stable shrinkage trend. As a whole, the shrinkage value of the standard specimen is smaller than that of the medium and large specimen, but the value is smaller than that of the large specimen, only 5×10^{-6}.

![Figure 1](image1.png)  
**Figure 1.** Effect of different specimen sizes on autogenous volume deformation of concrete. 
*S, M and L show that the standard specimen, medium specimen, large specimen and so on.*

![Figure 2](image2.png)  
**Figure 2.** Effect of different specimen sizes on autogenous volume deformation of concrete with 6% of MgO.
As it can be seen from the results of Figs 2-4, the sizes of test specimens have obvious effects on the value of volume deformation of mixture MgO concrete. The general trend is that the measurement value of volume deformation of mixture MgO concrete decreases with the increase of sizes of the test specimen, standard specimen>medium specimen>large specimen. For instance, when it is with 6% of MgO, the measurement values of volume deformation of standard specimen, medium specimen, and large specimen at the age of 180 days are $36 \times 10^{-6}$, $32 \times 10^{-6}$, $27 \times 10^{-6}$, comparing large specimen with standard specimen and medium specimen, the values decreased by 15.6% and 25.0% respectively; similarly, when it is with 10% of MgO, the measurement value of volume deformation of the concrete for the standard specimen increases by $(5 \sim 12) \times 10^{-6}$ than that of medium specimen before 200 days, and increases by $20 \times 10^{-6}$ after 200 days; Similarly, the measurement value of volume deformation of the concrete of medium specimen increases by $(3 \sim 8) \times 10^{-6}$ than that of large test specimen before 200 days and increases by $10 \times 10^{-6}$ after 200 days, which means that the growth
between standard specimen and medium specimen is significantly higher than that between the medium specimen and large specimen. The differences between standard specimen and medium specimen are that the length of radical direction is increased by 50mm and the height is the same and the differences between medium specimen and large specimen are that the length of vertical direction is increased 100mm, the length of radical direction is the same, which prove that changes in the length of radical direction have a greater effect than that of the length of vertical direction on the measurement value of volume deformation of the concrete; on one hand, the changes of the length of radical direction may have larger constraining force on the volume deformation of the concrete than that of the length of vertical direction; on the other hand, the aggregate whose grain diameter is greater than 40mm has not been filtered out when the standard specimen has been molded, whereas, when the medium specimen and large specimen are molded, the aggregate whose grain diameter is greater than 40mm has been filtered out, then the MgO content in unit volume of standard specimen is more than that of the medium specimen and large specimen, resulting in more swelling deformations of standard specimen than that of the medium specimen and large specimen [8]. Of course, there also exists the other reasons that the grain diameter of aggregate in medium specimen and large test specimen is larger than that of in standard specimen, the compatibility between aggregate and cement paste interface decreased, consequently, swelling capacity caused by the hydration of a part of MgO absorbed, leading to the effective swelling capacity decreased [9].

- As it can also be seen from the results of Figs 2-4, the sizes of test specimen have no obvious effect on the deformation rate of the MgO concrete. The deformation rates of the three sizes are the same on the whole, but the deformation rate is a little larger before 180 days, after that, the deformation rate begins to decrease with the age. For example, the standard specimen mixed 8% of MgO, when the concretes are at 60 days, 180 days, 300 days, the corresponding measurement values of volume deformation are $33 \times 10^{-6}$, $60 \times 10^{-6}$, $68 \times 10^{-6}$; the deformation rate has been decreased from $0.23 \times 10^{-6}$/day before 180 days to $0.07 \times 10^{-6}$/day after 180 days.

- The results of Figs 2-4 prove again that no matter the size is large or small, the aggregate whose grain diameter is larger than 40mm or not, the volume deformation of MgO concrete increases with the increase of MgO mixture, and increases slowly with the age. Lu pointed out that the growth of Mg(OH)$_2$ crystal had been filled the holes of the concrete, which lead to the dense structure of concrete [10]. Before 28 days, the concrete is dramatically swelled. Between the age of 60 days and 200 days, the slope of swelling process of MgO concrete in three sizes reaches a maximum; the rates of deformation reduced after the age of 200 days, the deformation of concrete does not occur reduced with ages [11]. For instance, at the age of 360 days, when 6% of MgO is mixed, the measurement values of volume deformation of standard specimen, medium specimen and large specimen are $50 \times 10^{-6}$, $44 \times 10^{-6}$ and $38 \times 10^{-6}$; when 10% of MgO is mixed, the measurement values of volume deformation of stand specimen, medium specimen and large specimen are $104 \times 10^{-6}$, $84 \times 10^{-6}$ and $76 \times 10^{-6}$, which respectively increases by 108%, 91%, 100% than that of 6% of MgO.

This reason is that the increase of MgO mixture increases the amount of Mg(OH)$_2$ crystal created by hydration reaction, and the corresponding pressure and swelling force of crystal growth lead to the deformation of concrete. As for the expansive action, Charterji believed that the expansion power of cement paste originates from the pressure of crystal growth created by MgO hydration reaction [12], the hydration reaction of the early age of MgO was rather intensive, the reaction speed was fast, elasticity modulus of the concrete at this time is rather low, which all contributed to the increase of deformation rate of MgO concrete; at the late age of MgO, once the hydration reaction came to an end, the dilatational strain was over, so the deformation of MgO concrete increased slowly with the extend of the age, but it would gradually become stable eventually.

- The influence of sizes of the test specimen on the interior pore structure of MgO concrete. The volume deformation of the test specimen of MgO concrete is not only related to the MgO mixture, but also relevant with porosity, including the average pore size and pore size distribution. It is always the outcome of multifactor. The larger proportion that the harmful
pores and multiple damage pores inside concrete take, the bigger of the interior porosity and average pore size, then the degradation of interior structure of the concrete [13]. Al-Tabbaa pointed out that the influence of MgO concrete deformation mainly depended on the microstructure inside the concrete [14]. According to the pore sizes, the Wu indicated that the interior pore of the concrete was as follows: damage pores (>200 nm), harmful pores (50 nm ~ 200 nm), less harmful pores (20 nm ~ 50 nm) and harmless pores (<20 nm) [15].

As can be seen in Table 5, when the MgO has not been mixed, the size order of the interior structure of the concrete is as follow: large specimen (11.47%) > medium specimen (9.65%) > standard specimen (1.46%). Accordingly, the measurement values of shrinkage of the large specimen, medium specimen and standard specimen at the age of 360 days are 18×10^{-6}, 15×10^{-6}, 14×10^{-6}, which has proved that the shrinkage of the volume deformation become bigger with the increasing of interior porosity of concrete, When mixed with 6% of MgO, the interior porosity of the standard specimen of the concrete (13.04%) is smaller than that of medium specimen (14.51%), the measurement value of dilatational strain of the volume of the test specimen is smaller than that of standard specimen, which is shown in Fig2. This is because the larger interior porosity of the concrete can absorb more MgO than that of the smaller interior porosity of the concrete, which results in the reducing of the ultimately valid swell capacity of MgO concretes. Meanwhile, when mixed with 6% of MgO, the proportion of the harmful pore and multiple damage pore inside the large specimen and medium specimen is 45.44% and 26.5%, both the harmful pore and multiple damage pore absorb the hydration products of MgO, leading to the measurement value of the volume deformation decreases with the increase of the size, which is shown in Fig2. When mixed with 8% of MgO, the interior porosity of the concrete of the standard specimen and medium specimen is 13.52% and 15.14%, the proportion of harmful pore and multiple damage pore is 28.17% and 32.89%, leading to the measurement value of the volume deformation decreases with the increase of the specimen size; which is shown in Fig3. When mixed with 10% of MgO, the interior porosity of the concrete of the standard specimen (9.83%) is the smallest, the medium specimen (17.30%) and large specimen (17.22%) are much larger than that of the standard specimen, and the porosity of medium specimen and large test specimen are very close. Therefore, Fig4 also shows that the measurement values of the volume deformation decrease with the increase of the specimen sizes.

4. Conclusions
The specimen size has an obvious influence on the autogenous volume deformation of MgO concrete. It is largest for the standard specimen, then the medium specimen and the third the large specimen. Besides, changes in radical dimension of the test specimen have a more obvious influence on the measurement value of autogenous volume deformation of MgO concrete than that of the vertical dimension.

The specimen size also has an influence on the interior the pore structure of MgO concrete. The larger size of the specimen, the worse parameter values of the pore structure of the concrete; otherwise, the smaller size of the specimen, the better parameter values of the pore structure of the concrete. Changes of the parameter values of the porosity character inside the test specimen are the internal causes for autogenous volume deformation of MgO concrete with different sizes.

Once again, the autogenous volume deformation of MgO concrete increases with the increase of MgO mixture is verified; the deformation rate of MgO concrete is larger at the early age, then it becomes slower at the later age and stable eventually.

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