Influence of length-to-diameter ratio on shrinkage of basalt fiber concrete

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Abstract. In order to study the shrinkage performance of basalt concrete, using the shrinkage rate as index, the work not only studied the influence of different length-to-diameter ratio (LDR) on plastic shrinkage and drying shrinkage of basalt fiber concrete, but also analyzed the action mechanism. The results show that when the fiber content is 0.1%, the LDR of 800 and 1200 take better effects on reducing plastic shrinkage, however the fiber content is 0.3%, that of LDR 600 is better. To improve drying shrinkage, the fiber of LDR 800 takes best effect. In the concrete structure, the adding basalt fibers form a uniform and chaotic supporting system, optimize the pore and the void structure of concrete, make the material further compacted, reduce the water loss, so as to decrease the shrinkage of concrete effectively.

1. Introduction

Concrete shrinkage refers to the phenomenon of concrete volume shrinkage in the initial condensation or during hardening. Generally including plastic shrinkage, chemical shrinkage, drying shrinkage and carbonation shrinkage, large shrinkage will cause the concrete cracking, which has the most significant impact on the plastic shrinkage and drying shrinkage of concrete. Shrinkage is mainly related to the properties of raw materials, mix ratio, curing methods and so on. Excessive and uneven shrinkage will produce internal stress and even cracks in the product and component, which will affect the quality and durability of concrete [1]. As a new material of inorganic fiber, basalt fiber has many strong points, including high temperature resistance, corrosion resistance, alkali resistance, strong chemical resistance, good thermal stability and other advantages, therefore, in the construction industry. Basalt fiber plays a unique role in enhancing the shrinkage of concrete [2]. At present, there are a lot of researches on the influence of basalt content on the shrinkage of concrete, but for the influence of the length to diameter ratio (LDR) is relatively few. So this paper studied and analyzed the drying shrinkage properties and plastic shrinkage properties of basalt fiber, in order to figure out the influence of different LDR of basalt fiber on dry shrinkage properties and plastic shrinkage properties of concrete and provide reference for its engineering application.

2. Raw Materials and Experiments

2.1 Raw Materials
(1) Cement: P • O 42.5 cement produced by Ningxia Sai Ma Cement Factory.
(2) Sand: fineness modulus 2.32, meet the II zone level, mud content of 2.0%, clod content of 0.8%.
(3) Coarse aggregate: gravel, continuous gradation, maximum particle size is 20 mm, mud content of 0.45%, clod content of 0.3%, crushing index of 9.8%, needle sheet content of 7.3%.

(4) Fiber: Nanjing Mandecard Technology Co., Ltd. Produced the basalt fiber, length is 12 mm, the actual fiber density is 2.65 g/cm³.

(5) Gelatine Powder: VINNAPAS RE5044N, Dispersible vinyl acetate-vinyl copolymer powder, white powder, produced by Germany Warker, its solid content of 99%, apparent density of 490 kg/m³, needle sheet content of 7.3%.

(6) Water reducer: naphthalene series superplasticizer, brown yellow powder, solid content of >92%, 0.3% of the amount of cementitious material, the recommended dosage of 0.75%.

2.2. Test Plan
Considering the performance requirements of concrete, the slump is controlled at 80mm to 120mm. Using single-factor test program, after several trial mixing, determined the basalt fiber concrete mix ratio (Table 1).

| TABLE 1. Mix proportions design of basalt fiber concrete. |
|----------------------------------|----------|----------|----------|----------|----------|----------|
| numbe r | cement | gelatine powder | sand | gravel | LDR(volume content) | water | water reducer /% |
|---------|--------|-----------------|------|--------|---------------------|-------|-----------------|
| XW-1    | 400    | 16              | 638  | 1186   | 0                   | 160   | 0.75            |
| XW2-1   | 400    | 16              | 637  | 1184   | 400(0.1%)           | 160   | 0.75            |
| XW3-1   | 400    | 16              | 637  | 1182   | 600(0.1%)           | 160   | 0.75            |
| XW4-1   | 400    | 16              | 636  | 1180   | 800(0.1%)           | 160   | 0.75            |
| XW5-1   | 400    | 16              | 635  | 1179   | 1000(0.1%)          | 160   | 0.75            |
| XW6-1   | 400    | 16              | 634  | 1177   | 1200(0.1%)          | 160   | 0.75            |
| XW2-2   | 400    | 16              | 637  | 1184   | 400(0.3%)           | 160   | 0.75            |
| XW3-2   | 400    | 16              | 637  | 1182   | 600(0.3%)           | 160   | 0.75            |
| XW4-2   | 400    | 16              | 636  | 1180   | 800(0.3%)           | 160   | 0.75            |
| XW5-2   | 400    | 16              | 635  | 1179   | 1000(0.3%)          | 160   | 0.75            |
| XW6-2   | 400    | 16              | 634  | 1177   | 1200(0.3%)          | 160   | 0.75            |

Note: (1) the amount of fiber in the brackets is the percentage of the total volume of the fiber;
(2) The amount of the water-reducing agent is the mass percentage of the cementitious material.

2.3. Experimental Method
According with the standard test methods of long-term performance and durability of ordinary concrete(GB/T 50082-2009) on shrinkage test contact method, preparation of 100mm ×100mm×515mm shrinkage specimens, after 3d standard curing temperature, removed the products in a constant temperature and humidity environment, which temperature is (20±2)°Cand relative humidity of (60±5)%. Measured the initial length immediately, thereafter, according to 1d, 3d, 7d 14d, 28d, 45d, 60d, 90d of time interval (contraction age), measure each length of products, and calculate the shrinkage rate respectively. The plastic shrinkage was carried out using non-contact method, and the deformation was measured continuously for 72 hours after molding.

3 Test results and analysis
3.1. Effect of LDR on Plastic Shrinkage of Basalt Concrete
FIGURE 1. At 0.1% when different dosage of fiber LDR on basalt plastic shrinkage of concrete

FIGURE 2. At 0.3% when different dosage of fiber LDR on basalt plastic shrinkage of concrete

It can be seen from Figure 1 and Figure 2 that the effect of basalt fiber on plastic shrinkage crack is better when the ratio of fiber is 0.1% and the LDR are 800 and 1200. When the aspect ratio is 800 of basalt fiber, the effect is the best, the plastic shrinkage of concrete is only $182 \times 10^{-6}$. When the fiber content is relatively much at 0.3%, the shrinkage age is within 11h, the basalt fiber with the LDR of 800 has the best effect, and the shrinkage rate is kept between $(0-50) \times 10^{-6}$, but overall, when the LDR is 600 of the basalt fiber, effect is relatively good, the shrinkage rate at 72h is $290 \times 10^{-6}$.

According to the study by Banthia [3], the fracture area and the maximum crack width are inversely proportional to the aspect ratio of the fiber:

$$A_c = \alpha \left( \frac{1}{d} \right) \quad (1) \quad W_{\text{max}} = \beta \left( \frac{1}{d} \right) \quad (2)$$
But the proportion coefficient $\alpha$ and $\beta$ vary with the fiber content. The total surface area of fiber per unit volume ($S_f$) can also be used as a parameter to reflect the crack area and the maximum crack width. But the relationship between them are exponential \[^{[4]}\].

$$A_c = \alpha e^{-bS_f} \quad (3)$$
$$W_{max} = A e^{-bS_f} \quad (4)$$

It can be seen that the effect of LDR of 1200 and at 0.3% when aspect ratio of 400 and 600 is relatively good, which is basically consistent with the conclusion of this experiment.

3.2. Effect of LDR on Drying Shrinkage of Basalt Concrete

As can be seen from Figure 3 and figure 4. For the drying shrinkage, the shrinkage of concrete is the most obvious when the LDR is 800. This is due to the three-dimensional chaotic distribution of basalt fiber in the specimen. The length of the basalt fiber with the LDR of 1000 and 1200 is relatively large, LDR 600 and 400 are kind of short, the side wall effect \[^{[5]}\] is relatively strong (The side wall effect is that fiber in between the mold and the aggregate or next to the surface of side wall, due to the restriction of the edge wall, the fiber tends to parallel to the direction of the side wall). Basalt fiber along the coarse aggregate interface cannot resist cracks. However, the side wall effect of basalt fiber with the aspect ratio of 800 is relatively weak, and there is a certain amount of basalt fiber intersects with the interface of cemented aggregate. Once the initial microcracks that parallel to the interface have a trend to develop, this part of basalt fiber can prevent its development very well, delayed the formation of initial micro cracks, and effectively restrained the shrinkage of concrete.

![Figure 3](image_url)

**FIGURE 3.** At 0.1% when different dosage of fiber LDR on basalt drying shrinkage of concrete
4 Mechanism analysis

There are two kinds of theories about the crack resistance mechanism of fiber, from different angles to explain this mechanism. Firstly, Romuadi from the United States proposed "fiber spacing theory"[6], according to the fracture mechanics theory to explain that fiber plays a role in the crack resistance for cracks of concrete, to improve the strength of concrete, must reduce the number and scale of cracks and the original defects in concrete, when the fiber spacing less than a certain value, the tensile strength of concrete will be increased. Secondly, Swamy from the United Kingdom proposed "composite theory"[7], starting from the composite principle that constituted by composite materials, considering fiber as a concrete strengthening system, applying the composite principle to deduce the tensile strength of fiber reinforced concrete, put forward a relationship among the tensile strength of fiber concrete and the amount, the direction, the LDR and the bond force of fiber.

Fiber spacing is more suitable to explain the plastic crack resistance mechanism of fiber concrete. Before the concrete is not hardened, the fiber has the effect of crack resistance. There are tens of millions to hundreds of millions of fibers per unit volume of concrete, the effect of crack resistance of fiber is mainly reflected in the number of fibers, the smaller the spacing between fibers, the more obvious the effect of the early anti-cracking. When the fiber spacing is large enough to a certain value, the fiber has little effect on the early crack resistance of concrete. When the fiber content is same, in the premise of ensuring the full dispersion of fiber, from the point of view of anti-cracking, it is appropriate to use fine fibers. When the fiber content is certain, the fiber content more thinner and the number of fibers in the unit volume concrete is numerous, the effect of crack resistance is more remarkable. The fiber length should be adapted to the size of coarse aggregate, for the larger diameter of coarse aggregate, we should select longer fiber.

In the concrete structure, the addition of fiber in the concrete to form a uniform and chaotic supporting system, optimizing the concrete pore and the void structure, reducing the number of capillary and internal porosity, making the material more compact, reducing the water loss, so as to reduce the shrinkage of concrete effectively.

At the same time, because of the elastic modulus of the fiber is big, it counteracted the pressure of capillary, thereby reducing the total capillary pressure. So the addition of fiber significantly reduced the shrinkage of concrete.
5 Conclusion
(1) The effect of basalt fiber on plastic shrinkage crack is better when the ratio of fiber is 0.1% and the LDR are 800 and 1200. When the LDR is 800 of basalt fiber, the effect is the best, the plastic shrinkage of concrete is only $182 \times 10^{-6}$. When the fiber content is relatively at 0.3% and the LDR is 600 of the basalt fiber, effect is relatively good, the shrinkage rate at 72h is $290 \times 10^{-6}$.

(2) For the drying shrinkage performance of concrete, the LDR of 800 basalt fiber takes good effect on suppressing shrinkage.

(3) In the concrete structure, the addition of fiber in the concrete formed a uniform and chaotic supporting system, optimizing the pore and the void structure of concrete, making the material more compact, reducing the water loss, so as to reduce the shrinkage of concrete effectively.

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References
[1] Li Shihua. Influence of Admixtures on Shrinkage Property and Cracking Behavior of Concrete [J]. Zhengzhou: Zhengzhou University, 2012.
[2] Wang Xingzhou. Research on the plastic shrinkage of fiber concrete [D]. Jilin: Jiling University, 2006.
[3] Nemkumar Banthia and Cheng Yan, Shrinkage Cracking in Polyolefin Fiber-Reinforced Concrete. ACI Materials Journal, V. 97, No.4, July-August 2000.
[4] Kang Jingfu. Shrinkage of concrete at early age and approach on the anti-cracking mechanism of polypropylene fiber. Concrete, 2013, 159 (1):10-12.
[5] Xu Ping, Cui Jian. Effect of fiber - aspect ratio and content on compressive strength of steel fiber reinforced concrete [J]. Manufacturing: material, 2004, 42(482) : 60-61.
[6] Hu Xiaoqing, Wang Yongsheng. Defect Analysis of Theory of Fiber Spacing [J]. An Hui Construct, 2011, (02): 73-74.
[7] Li Jianqiang. Experimental research on Ultra High Toughness Cementitious Composites [D]. Chang An university, 2012.