Study on the development characteristics of concrete strength under early age load

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ABSTRACT. *In this paper, the development of concrete strength characteristics under the load of early age is studied through experiments. The results show that: the compressive strength and splitting tensile strength of concrete will deteriorate after early age load, but the deterioration effect will be weakened with the extension of initial loading time. For the concrete that began to be loaded at the age of 1d, the incorporation of fibers further aggravated the damage to the concrete caused by the early-age load, and did not have the effect of increasing the strength characteristics, however, for the concrete that began to be loaded at 3d, the incorporation of fibers can effectively reduce the damage to the concrete caused by the early-age load.*

KEYWORDS: *early age load, basalt fiber, strength characteristics*

1 Introduction

Since its inception in the 1860s, concrete has experienced more than a century of development and has become one of the most widely used building materials in today's construction projects, it plays a pivotal role in all types of projects. The construction of concrete structure has to go through many processes such as mixing, conveying, pouring, vibrating and flattening, and it needs to be maintained at 20±2℃ and 95% humidity for 28 days in order to meet its design strength and stiffness requirements. However, in practical engineering, concrete often has to undergo all kinds of loads after pouring. At this time, the bearing capacity of concrete is far from meeting its design requirements, so it is prone to safety and quality accidents.

In recent years, with the gradual depletion of shallow coal mine resources, coal mining has gradually moved closer to the depth. As the "throat" of coal engineering, vertical shaft connects the ground and underground, playing the role of transportation, ventilation and so on. Therefore, shaft safety is an important guarantee for efficient mining and the safety of coal miners' lives and property. Freezing shaft sinking is the most effective excavation method in the process of vertical shaft construction, during the construction period, the inner wall of the concrete structure will bear the self-weight of the shaft wall, and the outer wall will

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also be subjected to early loads such as freezing pressure, thermal stress and so on, these loads increase with the increase of the thickness of the shaft through the flushing base, and once the load reaches a certain limit, the concrete sidewall structure will be damaged when it does not reach its design strength. It leads to the cracking and aggregate separation of the structure, which directly leads to the decrease of the impermeability of concrete, and leads to new damage to the concrete. Wang [1] and other studies have shown that at a depth of 500 meters in the Longgu Mine, the freezing pressure on the concrete can reach more than 10MPa, which is about 30% of the 7d strength of C40 concrete. Will such a large early load affect the concrete structure, the potential safety hazards are issues that have to be considered in the design of engineering structures. In other construction projects, such as the early age loading behavior of high-grade concrete is already common, in order to ensure the construction progress, the construction of the next process is often carried out after the concrete is poured. The beams, columns and other members of this construction layer have to bear not only the self-weight of the structure, but also the weight of the construction personnel and equipment. For example, the aluminum alloy formwork is generally removed when the age reaches 36 hours, but the concrete is far from meeting the requirements of its design strength and stiffness. At this time, whether the concrete in the early age state will be damaged under the construction load and whether the damage will have an impact on the structure of concrete in the later stage, these are all issues of great concern in the engineering application of early dismantling support system of aluminum alloy formwork.

Therefore, mastering the law of strength and load variation of concrete after it is disturbed by external load at its early age is to ensure the safe operation of concrete structure, improve the quality and construction progress of concrete, and realize the foundation that concrete can serve in the construction project for a long time. This paper takes ordinary concrete and fiber reinforced concrete under early age load as the research object, studies the influence of early age load on the later mechanical properties of concrete, and scientifically evaluates the damage of concrete under early age load, in order to provide reference for the design and construction of concrete structure.

2 Test material and scheme

2.1 Raw materials

The cement is made of Bagongshan brand P.O32.5 ordinary Portland cement, the fine aggregate is made of Huaibin river sand with a particle size of 2.9, the coarse aggregate is made of limestone macadam with a particle size of 5-13mm, and the fiber is made of BC3-12 basalt fiber. The proportion and fiber characteristic index of concrete are shown in Table 1 and 2.

Table1 Proportion of concrete

Group	Water cement ratio	Sand ratio	Material consumption($kg \cdot m^{-3}$)				
			Cement	water	Sand	Stone	Fiber
Ordinary concrete	0.46	37%	380	176	662.11	1151	/
Fiber reinforced concrete	0.46	37%	380	176	662.11	1151	0.15%

Table 2 Characteristic parameters of basalt fiber

Length(mm)	Filament diameter(μm)	sintering temperature(℃)	Modulus of elasticity(GPa)
24	7-15	1050	91-110

Figure. 1 Basalt fiber

2.2 Test scheme

First of all, four series of concrete specimens are made according to the mix ratio of Table 1, including two series of ordinary concrete and two series of fiber reinforced concrete. Each series includes 9 cube specimens under continuous compression at early age and 9 reference group contrast specimens. In addition, a number of specimens are reserved to measure their compressive strength at the age of 1d, 3d and 7d respectively as the reference value of applying early age load.

The early age load of 40% compressive strength of the same age is applied to the concrete test block at the age of 1d and 3d, respectively, and the load needs to be further increased to 40% of its compressive strength at 7d. In order to ensure the loading effect and prevent the early age load from weakening, the concrete is

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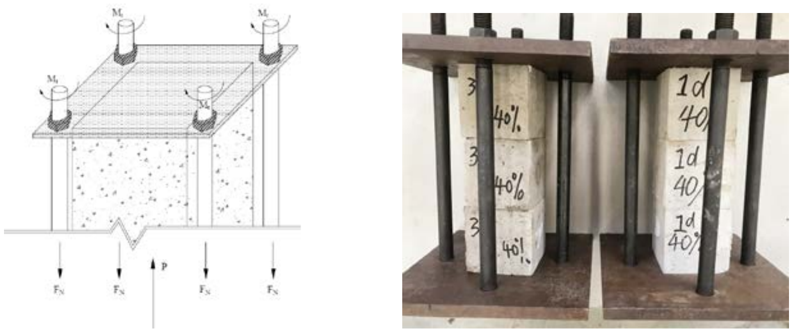
pressed every 1.5d, and the load level is consistent with the load level of 7d. In the process of setting and hardening, concrete itself will produce self-shrinkage effect due to various reasons [2], and after 15d, the compression effect of the loading device is not good and has little effect on the strength of concrete, so the loading device is removed after 15d. During the period, the natural curing method is adopted in the concrete.

A self-made early age loading device is used to simulate the stress of concrete at early age. the device is composed of two steel plates, four hexagonal screws and nuts, a torque wrench and a matching custom sleeve. The test load tightens the nut by a torque wrench with sufficient range, so that an extrusion load will occur between the two steel plates, so that the concrete specimen in the middle of the compression plate is subjected to compressive stress, and the pressure transmitted by the screw to the steel plate is determined by the following Formula.

$$M_t = 0.2 F_N D \qquad (1)$$

In this formula: Mt is torque, N·m; F_N is screw pretightening force, N; D is screw diameter,m.



(a)Stress analysis *(b)Early age load*

Figure. 2 Self-made loading device

According to Formula (1) and Figure 2: Mt=0.2F_N·D; D=22×10^{-3}m; F_N=P/4; Mt=0.2×P/4×22×10^{-3}; M_t, N·m; P, N.

3 Test results and analysis

According to the above test scheme, the compressive strength and splitting tensile strength were tested after loading for 1d and 3d and curing for 28 days in the corresponding benchmark group. The test results are shown in Table 3.

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Table3 Compressive strength of loaded specimens at early age

Specimen	Compressive strength(MPa)	Splitting tensile strength(MPa)
X-1d-40	29.3	2.74
X-3d-40	34.11	3.01
X-Reference group	36.17	3.16
C-1d-40	30.3	2.56
C-3d-40	32.6	2.71
C-Reference group	35.4	2.93

Note: C represents ordinary concrete, X stands for fiber reinforced concrete,1d and 3d represent the beginning of loading time, and 40 represent the horizontal ratio of applied load.

It can be seen from the above table that when ordinary concrete is subjected to an early age load of 40% of its compressive strength at its age of 1d or 3d, both the compressive strength and the splitting tensile strength are reduced. For the C-1d-40 series specimens, the compressive and split tensile strengths are 85.5% and 87.3% of the specimens that have not been subjected to the early-age load. With the extension of the initial holding time, the attenuation amplitude decreased, the compressive and splitting compressive strengths of the specimens that began to hold the load at 3 days were 92.0% and 92.4% of the specimens that were not subjected to the early-age load. This shows that when concrete is subjected to external loads at its early age, its strength characteristics will deteriorate, but as the initial holding time increases, the deterioration effect will be reduced. The reason for this phenomenon is: when the age is 1 day, the concrete only initially forms the bearing capacity, and when 40% of the early age load is applied, the primary pore cracks in the concrete suddenly increase, the new cracks develop rapidly, and produce irreversible damage to the internal structure of the concrete. finally, the 28-day strength decreases greatly. For C-3d-40 specimens, due to the late loading time, the internal pore development of concrete ushered in a quiet growth period of 3d, and its compressive strength was high enough when it began to load in 3d, compared with the specimen loaded at 1d, its resistance to external load was improved, but because the load was still large and the internal pore structure was still destroyed. Therefore, the 28day compressive strength is lower than that of the base group, but better than that of 1d specimens.

In addition, comparing the fiber group concrete with the ordinary concrete reference group, it can be found that the addition of fiber can enhance the compressive strength and splitting tensile strength of unloaded concrete, and the two strengths increase by 2.1% and 7.8% respectively compared with ordinary concrete. this phenomenon is consistent with the studies of many scholars [3]. Because the strength of fiber reference group is higher than that of ordinary concrete, only the strength reduction can not better reflect the effect of fiber addition on the strength change characteristics of early age loaded concrete. Therefore, in order to better reflect the influence of basalt fiber on the development of strength characteristics of early age loaded concrete, the strength attenuation percentage is introduced to describe the effect of basalt fiber on the strength of concrete.

$$\sigma_{\%} = \frac{\sigma_J - \sigma_S}{\sigma_J} \qquad (2)$$

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$\sigma_{\%}$ is Strength attenuation percentage,%; σ_J is 28d compressive or splitting tensile strength of reference group, MPa; σ_S is 28d compressive or splitting tensile strength of loading group, MPa.

According to the above formula, the attenuation percentage of 28d compressive strength and splitting tensile strength of concrete is calculated, as shown in Figure 3..

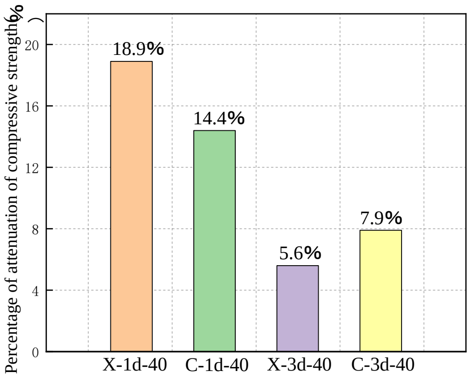

Figure.3 Attenuation percentage of compressive strength

It can be seen from the figure that after the basalt fiber reinforced concrete is subjected tothe early age load of 40% of its strength at the age of 1d, the 28-day compressive strength of the basalt fiber reinforced concrete is 18.9% lower than that of the unloaded specimen, while t he compressive strength of the specimen loaded at 3-day age is lower than that of the unloaded specimen, but the decrease is less than that of 1 d, and 5.6% lower than that of the unloaded specimen.This shows that the compressive performance of basalt fiber reinforced concrete will deteriorate obviously within three days after its pouring, when it is subjected to an external load of 40% of its compressive strength at that time, but this phenomenon will be weakened with the extension of the initial loading time.

In addition, by comparing the compressive strength attenuation percentage of fiber reinforced concrete with that of ordinary concrete, it is found that the strength attenuation trend of the two kinds of concrete shows a decrease in strength after the early age load of 40% of their then strength is applied within three days after the completion of pouring, but the extent of reduction is obviously different between the two kinds of concrete .The main results are as follows: at1d age, the compressive strength of ordinary concrete subjected to early age load is 14.4%, while that of basalt fiber reinforced concrete is 4.5% higher than that of ordinary concrete. This shows that for the concrete loaded at the age of 1d, the addition of fiber further increases the damage degree of the early age load to the concrete, but does not have the gain effect on the strength characteristics. However, the percentage decrease of

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compressive strength of basalt fiber reinforced concrete subjected to early age load in 3d is 2.3% lower than that of ordinary concrete. It shows that the addition of fiber can effectively reduce the damage degree of concrete caused by early age load at 3d age, which is opposite to that at 1d age.

In order to study the effect of fiber addition on splitting tensile strength, the attenuation percentage of 28d splitting tensile strength of concrete is further calculated, as shown in Figure 4.

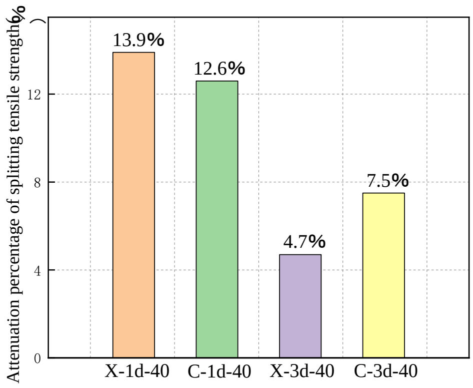

Figure. 4 Attenuation percentage of splitting tensile strength

It can be seen from the figure that the splitting tensile strength of basalt fiber reinforced concrete also shows a negative growth after the continuous action of early age load. compared with ordinary concrete, it can be found that the strength attenuation percentage of basalt fiber reinforced concrete loaded at 1d age increased by 1.3%, while that of concrete loaded at 3d age decreased by 2.8%. This trend is completely consistent with the changing characteristics of compressive strength. This further shows that fiber addition aggravates the damage degree of concrete structure for 1-day-old loaded concrete, while for 3-day-old loaded concrete, fiber addition can effectively weaken the effect of early age load on the mechanical properties of concrete.

According to the above experimental results, it is concluded that the reason for this phenomenon is: At the age of 1d, the bonding force between the concrete aggregate and the cementitious material is weak, and the amount of free water is still at the peak state of the entire curing age. At this time, the fibers are all over the concrete, and the surface of each fiber is not covered. the water molecules involved in hydration make the surface of the fiber smoother, which is equivalent to many "lubricating molecules" dispersed on the interface between the aggregate and the aggregate to reduce the bonding force between the materials. At this time, 40% of the early load further destroys the bond between the aggregates, causing a large number of micro-cracks in the concrete to appear. This damage is far greater than the damage suffered by ordinary concrete, and this damage cannot be repaired in the

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later curing process. Therefore, the attenuation percentage of compressive and split tensile strength is greater than that of ordinary concrete. At the age of 3d, the free water content inside the concrete decreases sharply, and the fibers gradually begin to play a role. A large number of fibers are evenly distributed on the concrete matrix to offset the internal stress, limit the development of microcracks and reduce the length of microcracks. The application of age load should reduce the bond between concrete aggregates, but due to the incorporation of fibers, tensile stresses appear in all directions inside the concrete, which inhibits the generation of cracks, delays and reduces mutual penetration,the appearance of cracks makes the strength of basalt fiber concrete decrease compared with ordinary concrete.

4 Conclusion

The main conclusions are as follows:

(1)When the load level of early age is 40% of the compressive strength of concrete at that time, the decrease of mechanical properties of concrete is more obvious, and the effect of loading time on the mechanical properties of concrete begins to show. The earlier the early age load is applied, the greater the weakening degree of the mechanical properties of concrete.

(2)The development characteristics of cube compressive strength and splitting tensile strength of basalt fiber reinforced concrete after early age load are studied. When the early age load level is 40% of its current compressive strength, its strength change shows the same trend as ordinary concrete.

(3)By comparing basalt fiber reinforced concrete with ordinary concrete by introducing the percentage of strength attenuation, it is found that for the concrete loaded at 1d age, the addition of fiber further aggravates the damage degree of concrete caused by early age load, it has no effect on the strength characteristic gain, but for the concrete loaded at 3 days, the addition of fiber can effectively reduce the damage degree of concrete caused by early age load.

References

[1] Y.S. Wang and L.B. Xue(2009). Measurement and analysis of freezing pressure of shaft wall in extra-thick alluvium[J]. Journal of geotechnical engineering, vol.31, no.2, p.207-212.

[2] J.H. Liu and J.Q. Wang(2014). Performance of shaft lining concrete with coupling action of early age frozen earth pressure and negative temperature[J]. Journal of Beijing University of Science and Technology, vol.36, no.8, p.1000-1006.

[3] Ludovico D M and Prota A(2010).Structural upgrade using basalt fibers for concrete confinement[J]. Composites of Construction, vol.5, no.14, p.541-552.