Mechanical Properties of Lytag Concrete Reinforced with Hybrid Fibers

Ming Zhang, Jiahua Jing, Shike Zhang

***Abstract*—Lytag concrete is a type of lightweight aggregate concrete fabricated by utilizing ceramic granules—produced from industrial by-products such as fly ash as coarse aggregates, provides an effective approach for fly ash utilization. However, the compromised mechanical performance and long-term durability of concrete resulting from ceramic granules incorporation significantly hinder the practical application and widespread adoption of Lytag concrete. In this paper, two different types of fibers were introduced in Lytag concrete and the inclusion of hybrid fibers significantly improved the mechanical properties and durability of the concrete. Through orthogonal experimental design, the effects of steel fiber, basalt fiber, and Lytag dosage on concrete performance were systematically investigated via experimental research, with comprehensive analysis identifying an optimal mix ratio. Building on the basis of optimized mixing ratios, the effect of variation in the amount of steel and basalt fibers on the compressive, tensile and flexural strengths was analyzed by varying the fibers dosage. The experimental results show that there is a significant correlation between the level of fiber dosage and concrete strength enhancement. In addition, the results of the durability tests also showed that hybrid fibers were very effective in improving permeability, creep resistance and early crack suppression. These findings suggest that hybrid fibers are a viable strategy for improving the performance of Lytag concrete in sustainable construction applications.**

***Index Terms*—Lytag concrete, mechanical properties, basalt fiber, steel fiber**

I. Introduction

CONCRET, the principal construction material for modern infrastructure construction, has demonstrated an irreplaceable foundational role in global engineering practices. Its applications have expanded from traditional housing construction to transportation infrastructure, water conservancy and power projects and other major livelihood areas, forming an all-round application system covering the main structure of the building, transportation networks, energy projects. While supporting the world's largest infrastructure construction, China's concrete industry is facing profound resource and environmental conflicts. As the global leader in concrete production, China's annual consumption of natural aggregates has surpassed 2 billion metric tons, accounting for approximately one-third of global construction aggregate extraction. This accelerated industrial expansion has unveiled critical systemic contradictions within the concrete sector. The first is the disparity between sustainable development and resource consumption; traditional concrete production mostly uses natural sand and gravel aggregates, which causes "sand shortage" in some places. The second is the conflict between industrial upgrading and lagging technology iteration; issues include low admixture of admixtures and irrational ratio design, among others. The third is the conflict between environmental preservation and production; currently, over 30% of the raw materials used in production are lost during the mixing, transporting, and building processes. Increasing environmental and resource issues are putting pressure on the sustainable development of the concrete industry [1-3]. Meanwhile, to meet stringent requirements of complex construction conditions and working environment, concrete is also developing in the direction of high strength, high crack resistance, high durability, and green environmental protection. The use of green and environmentally friendly high-performance concrete has become a prerequisite for environmental protection and the sustainable development of social resources [4-6].

Presently, conventional concrete production relies on extensive mining and quarrying, causing severe ecological harm through habitat destruction and biodiversity loss. Fly ash, an industrial by-product, although widely used as a cementitious supplementary material in Chinese concrete production, has the potential to impair material properties at increased dosages. Previous studies have shown that fly ash sintered into ceramic granules can replace non-renewable resources such as aggregates in construction, and this method can effectively increase the amount of fly ash in concrete by 21%-35% [7-11].Research on it began in China in the 1870s, and Liu Xunbo began studying the proportioning of Lytag concrete in 1987 [12]. The use of fly ash ceramic particles as coarse aggregate in concrete can greatly increase one-sided frost resistance, sulfate erosion resistance, and permeability [13-15]. The results of the study also showed that the modulus of elasticity, creep shrinkage and constitutive

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relations of Lytag concrete are comparable or even better than those of ordinary concrete. Although Lytag concrete has better durability, lightweight, and other characteristics, fatigue resistance, cracking, and tensile properties are still not ideal [10,12,17-18], brittle is still a bottleneck limiting the development of its application. The uplift problem of the lightweight aggregate is also one of the main challenges limiting the application and development of Lytag concrete. Improving the properties of concrete is usually achieved by changing its composition, with composite being the most common method. The introduction of better dispersed steel fibers into concrete can greatly improve its tensile strength, deformation resistance, heat resistance, and micro-and microstructure[18-20]. The incorporation of flexible fibers such as basalt and polypropylene into concrete significantly enhances its cohesion and structural integrity. The hybrid use of basalt-polypropylene fibers synergistically improves impact resistance while mitigating material brittleness, concurrently optimizing impermeability and freeze-thaw durability through enhanced micro-crack control. Studies [21-23] have shown that adding fibers to lightweight aggregate concrete has a considerable brittle reduction and toughening effect, which can increase the fracture resistance of Lytag concrete. However, the research is confined to single fibers such as steel or polypropylene, and there is no systematic examination of matching ratios in the current literature. In accordance with the previously mentioned study background and engineering requirements, this paper will discuss the use of the low dosage of steel fibers mixed with basalt fibers (rigid and flexible fiber composite materials) to reinforce Lytag concrete. Incorporating two or more different fibers into Lytag concrete not only brings into play the individual reinforcing effects of the fibers, but also the ability of a range of fibers to work in concert to achieve an admixture with complementary construction benefits. Steel fibers and basalt fibers can be used to prevent dry shrinkage cracks in concrete and boost its toughness. Meanwhile, the use of hybrid fibers improves the mechanical characteristics of light aggregate concrete and, to some extent, helps to mitigate the loss of concrete qualities. The aim of this study is to make full use of the synergistic effect of the mixed fibers and their interaction with the matrix to optimize the dispersion of fly ash ceramic particles in cement mortar, refine the microstructure of the cement paste, and significantly improve the overall performance of concrete. The results of this study will provide a solid theoretical foundation and empirical data for its practical application. In addition, the combination of fly ash ceramic particles as a green material with hybrid fibers reinforcement not only improves resource efficiency, but also significantly improves the basic mechanical properties of concrete, paving the way for more durable and environmentally friendly construction solutions.

II. Experimental Materials and Methods

A. Experimental Raw Materials

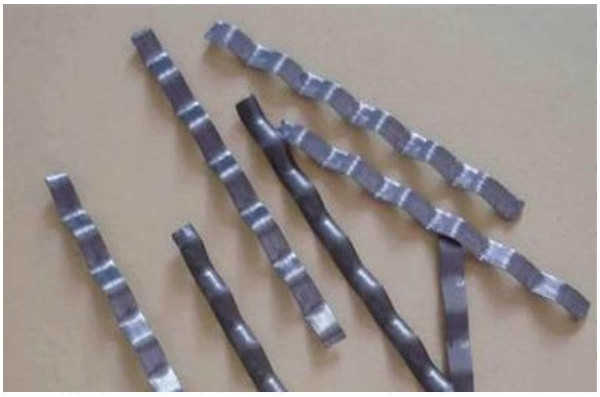
The fundamental engineering properties of concrete are intrinsically governed by its constituent composition, with all materials employed in this experimental study strictly complying with China's current regulatory standards for construction materials. Detailed material specifications are provided as follows:

(1) Cement: Cement has played an important part in the performance of mixed fiber reinforced Lytag concrete during preparation. Anyang Hu Bo Cement Plant P.O 42.5 grade ordinary silicate cement was used in this test.

(2) Water reducing agent: High-efficiency polycarboxylic acid liquid water reducing agent is used in this test, which is characterized by high water reducing rate, no air-entraining, small influence on setting time and good adaptability.

(3) Lytag: Zhengzhou Jinfeng Lytag was used in this test, which fits the requirements of the current national specification "Technical standard for application of lightweight aggregate concrete" [24]. The bulk density was 439 $kg \cdot m^{-3}$, the apparent density was 712 $kg \cdot m^{-3}$, the 1-hour water absorption rate was 10.5%, and the barrel compression strength was 4.5 MPa.

(4) Fiber: Steel fiber was 45 mm long and shear wave-type, whereas basalt fiber was 25 mm long and 17 μm in diameter. Figure 1 shows the fibers image.


(a) Steel fiber


(b) Basalt fiber

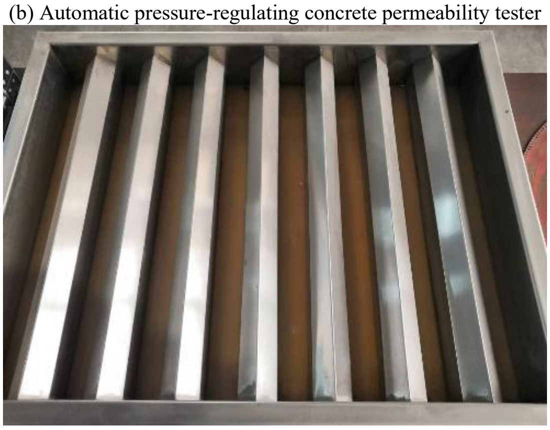
Fig. 1. Fibers type

B. Experimental Equipment

The primary experimental equipment utilized in this study are: 1) Mechanical properties experimental equipment: Mechanical properties were tested using the New Sans microcomputer-controlled hydraulic servo universal testing equipment; 2)Seepage Resistance Experimental Equipment: The seepage resistance tests were conducted using an HP-4.0 Automatic Pressure-Regulating Concrete Permeability Tester, manufactured by Shanghai East Star Equipment; 3) Crack resistance and strain experimental equipment: NELD-KL early cracking trial mould and NELD-CS710 concrete strain tester. Figure 2 shows photographs of the equipment.

(a) Microcomputer-controlled hydraulic servo universal testing equipment

(b) Automatic pressure-regulating concrete permeability tester



(c) Early cracking trial mould

(d) Concrete strain tester

Fig. 2. Main instruments and equipment

III. ORTHOGONAL EXPERIMENT

A. *Orthogonal design*

With the shortcomings of traditional single factor experiments, which are inefficient and difficult to reveal multi-factor interactions, the orthogonal design method was introduced in this experiment [25-26]. This method significantly improves the experimental efficiency through the mathematical principles of balanced dispersion and neat comparability. In the experiment, the volume fraction of steel fiber admixture was fixed at 0.5% in order to ensure the lightness of Lytag concrete. To set up the testing, the L9 (3^4) orthogonal table was chosen. Three factors were selected: cement amount, sand rate and basalt fiber amount. Each factor has three grades. Tables I and II show the factors, levels and concrete proportion design.

TABLE I
FACTORS AND LEVELS IN ORTHOGONAL DESIGN

Levels	Factors		
	A. Amount of Cement / kg·m^{-3}	B. Sand Rate	Basalt Fiber Dosage / kg·m^{-3}
1	420	36%	0.5
2	450	39%	0.8
3	480	42%	1.1

TABLE II
DESIGN OF THE CONCRETE MIX RATIO

Specimen Number	Cement / kg·m^{-3}	Sand / kg·m^{-3}	Lytag / kg·m^{-3}	Sand Rate	Basalt Fiber /kg·m^{-3}	Steel Fiber / kg·m^{-3}
FLC1	420	613.0	308.5	36%	0.5	39
FLC2	420	664.1	294.1	39%	0.8	39
FLC3	420	715.2	279.6	42%	1.1	39
FLC4	450	613.0	308.5	36%	0.5	39
FLC5	450	664.1	294.1	39%	0.8	39
FLC6	450	715.2	279.6	42%	1.1	39
FLC7	480	613.0	308.5	36%	0.5	39
FLC8	480	664.1	294.1	39%	0.8	39

B. Analysis of orthogonal experiments results

(1) Slump

Figure 3 shows the mean value of slump under the levels effect of each factor, from the figure, the degree of collapse with the increase of cement dosage firstly decreases and then increases, with the increase of sand rate and appear firstly increases and then decreases, basalt fiber dosage of the influence of the degree of slump also appeared to firstly decrease and then increase the phenomenon. Among the three factors, the sand rate had a greater effect on the degree of slump, and analysis of variance also confirmed that the sand rate had a more significant effect on the degree of collapse. It is suggested that it can be realized by the adjustment of sand rate when concrete has higher working performance requirements.

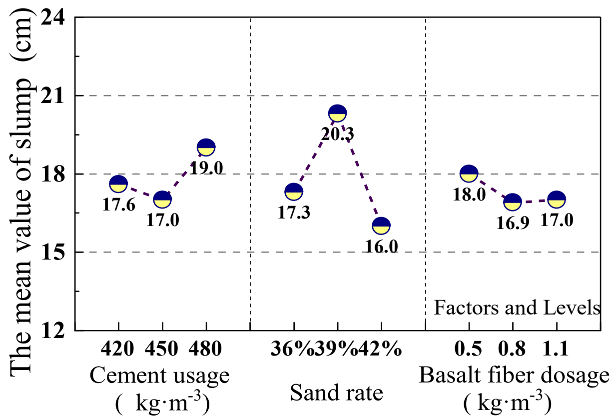


Fig.3. Mean value of slump

(2) Cubic compressive strength

Figure 4 shows the mean value of concrete cubic compressive strength under the level effect of each factor, which shows that the concrete cubic compressive strength increases with the increase of cement dosage, which is consistent with the effect of cement dosage on the compressive strength of ordinary concrete. At the same time, there is an initial increase and then a decrease in the concrete cubic compressive strength with the increase of sand rate. The extreme deviation of cement dosage is 16.1, sand rate is 10.3, and fiber dosage is 7.4. The cement dosage has the greatest effect on the cubic compressive strength, followed by sand rate and basalt fiber dosage.

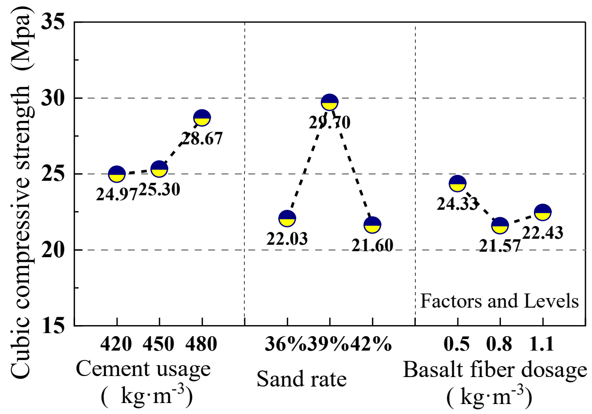


Fig.4. Cubic compressive strength

(3) Splitting tensile strength

Figure 5 shows the mean value of concrete splitting strength under the level of each factor , from the figure it can be seen that the concrete splitting tensile strength increases with the increase of cement dosage, at the same time, the concrete splitting strength will appear to increase and then decrease with the increase of sand rate, while under the influence of basalt fiber dosage, the splitting tensile strength increases with the increase of fiber dosage, which is mainly due to the antifracking effect of the fiber. After performing analysis of variance, it was found that the effect of each factor on the splitting tensile strength was not significant.

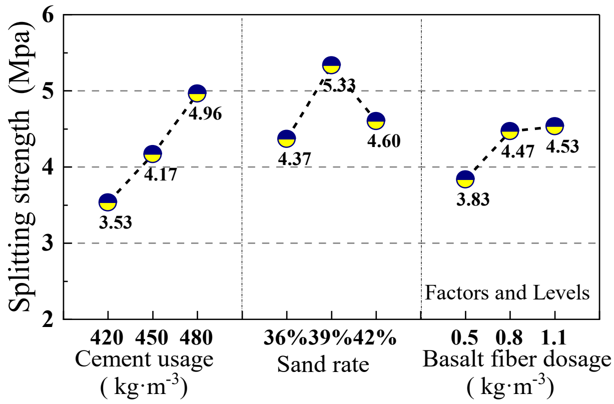


Fig.5. Splitting tensile strength

(4) Comprehensive analysis of multiple indicators

In the process of selecting the optimum concrete proportions, the importance of each index varies, as does the influence of each factor on different indexes. In this paper, the comprehensive balance method is used to determine the optimal mix ratio under three indicators in three steps: I) Calculate and analyze the measured indicators based on the single indicator to determine the optimal combination of its factor level; II) Conduct a comprehensive balance based on the importance of each indicator and its factor priority, as well as the level of superiority and inferiority of each indicator; III) Determine the overall optimal combination. The factor priorities and optimal levels of this experiment are shown in Table III.

TABLE III
FACTOR PRIORITIES AND OPTIMAL LEVELS

Indicator	Factor Priority	Optimal Level
Cubic Compressive Strength	A B C	A3B2C1
Slump	B A C	A1B2C1
Splitting Tensile Strength	B C A	A3B2C3

The comprehensive balance method's general principles are as follows: 1) The primary influencing factor of an indicator should be chosen when the superior level is present; 2) The superior level that appears more frequently should be chosen when a factor has little effect on the indicator; 3) For relatively important indicators, priority should be given to meeting the selection of the superior level of its factors. According to the above analysis, the combination of the optimum level of factors for the concrete proportion is A3B2C3.

TABLE IV
DESIGN OF THE CONCRETE MIX RATIO

Specimen number	Cement / kg·m^{-3}	Sand / kg·m^{-3}	Lytag / kg·m^{-3}	Sand Rate	Basalt Fiber / kg·m^{-3}	Steel Fiber / kg·m^{-3}
LC-J	480	664.1	294.1	39%	0	0
FLC-X00S05	480	664.1	294.1	39%	0	39
FLC-X05S05	480	664.1	294.1	39%	0.5	39
FLC-X08S05	480	664.1	294.1	39%	0.8	39
FLC-X11S05	480	664.1	294.1	39%	1.1	39
FLC- X11S00	480	664.1	294.1	39%	1.1	0
FLC- X11S10	480	664.1	294.1	39%	1.1	78
FLC- X11S15	480	664.1	294.1	39%	1.1	117

IV. ANALYSIS OF STRENGTH

A. Proportioning Parameters of Concrete

On the basis of the orthogonal experiment mentioned above, based on the optimal concrete mix ratio under the comprehensive three indexes, the influence of fiber content on the basic mechanical properties of hybrid fiber-reinforced Lytag concrete is systematically analyzed by changing the level of single-factor conditions. The experimental data provide reliable data support for the theoretical research and practical promotion of hybrid fiber reinforced Lytag concrete. the test hybrid fiber reinforced Lytag concrete mix ratio is designed in Table IV, in which the changes of steel fiber and basalt fiber content based on optimal concrete mix ratio was considered.

B. Analysis of cubic compressive strength

In accordance with “the national standard of test method for mechanical properties of ordinary concrete (Chinese standard)”[27], using 150mm×150mm×150mm cubic standard test blocks, each fit ratio to prepare 1 group of specimens, each group of 3, for a total of 27 specimens. A 1000kN hydraulic servo testing machine was used for this experiment. The loading speed was 0.5Mpa/s as specified. The observation and analysis of the compressive test revealed that the addition of fibers can effectively inhibit the tendency of concrete peripheral aggregate stripping in compressive damage, and that as the fiber admixture increases, so does the ability of concrete to resist deformation and cracking. Figure 6 depicts the growth trend of cubic compressive strength in Lytag concrete supplemented with mixed fibers for various single parameters. It is clear that when the amount of basalt fiber mixed increases, the cubic compressive strength remains relatively constant, showing that the basalt fiber has less impact on the cubic compressive strength of Lytag concrete. The addition of steel and basalt fibers to Lytag concrete can increase the concrete's compressive strength to a certain extent. However, whether the fibers are added in a single admixture or in combination, the increase in cubic compressive strength ranges from 3% to 11.4% when compared to the LC-J comparison group (Lytag concrete without fiber). This pattern is like the effect of fibers on ordinary concrete's compressive strength, and the enhancement effect of fibers on the concrete is not particularly significant.

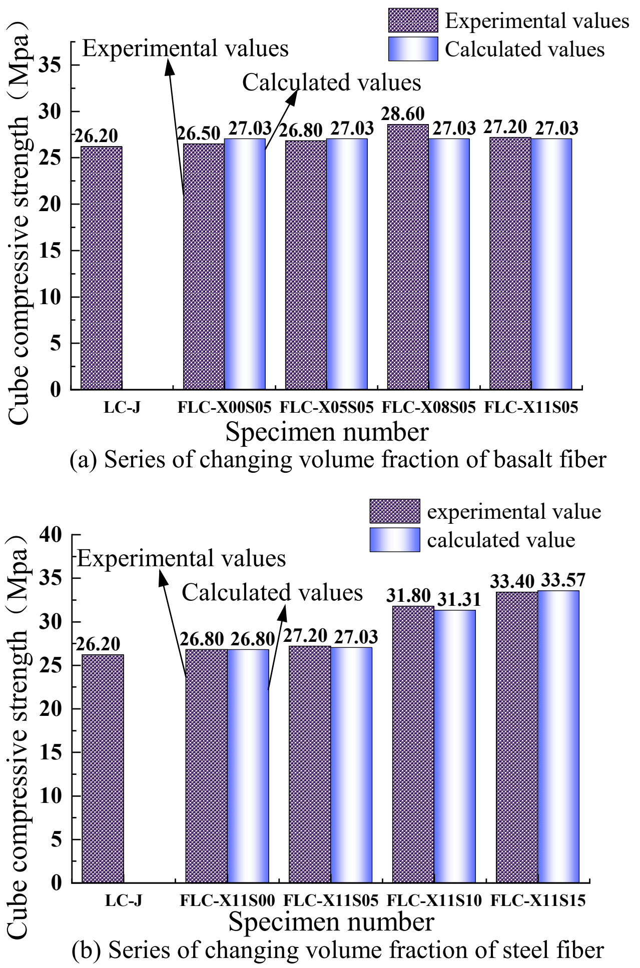


Fig.6. Experimental values and calculated values of cube compressive strength

According to the experimental data in this paper, taking into account the small influence of basalt fiber on the compressive strength of hybrid fibers reinforced Lytag concrete, the influence of basalt fiber is ignored in the calculation of cube compressive strength, and at the same time, taking into account the convergence with the strength of the current ordinary concrete, the formula for calculating the strength of mixed fiber-reinforced Lytag concrete cube is obtained through mathematical statistics shown in (1) .

$$f_{hzcu,0} = \alpha f_{cu,0} + \beta_f \lambda_f \quad (1)$$

Where $f_{hzcu,0}$ represents the cube compressive strength of hybrid fiber reinforced Lytag concrete, $f_{cu,0}$ represents the concrete cube design benchmark strength, α is the benchmark strength adjustment factor(according to this test can be taken as 1.07), β_f represents the steel fiber influence coefficient(according to the test data in this paper to take 0.824), in the experiment of different projects, but also according to the test can be determined. λ_f is the characteristic parameter of steel fiber, which can be calculated according to (2).

$$\lambda_f = \rho_f \, l_1 / d_e \quad (2)$$

In (2), ρ_f is the volume rate of steel fibers and l_1/d_e is the fiber aspect ratio. According to (1) and the relevant parameters of this experiment, the experimental and calculated values of the cube compressive strength of hybrid fiber reinforced Lytag concrete are obtained as shown in Figure 6, from which the calculated values are in good agreement with the experimental values.

C. Analysis of splitting tensile strength

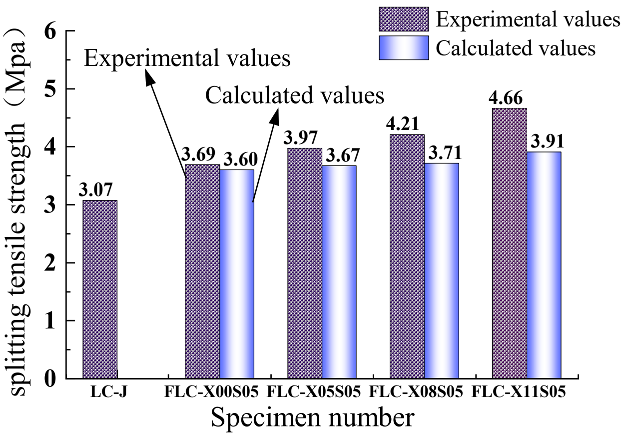
In accordance with the experimental parameter design in Table I, this test was carried out concurrently based on each mix ratio and produced standard specimen blocks measuring 150 mm by 150 mm by 150 mm for the splitting tensile test using Chinese normative test procedures. The split tensile strength trend of hybrid fiber reinforced Lytag concrete under various single parameters is displayed in Figure7. Figure7(a) shows that, in tests where the series of basalt fiber admixture was varied, the splitting tensile strength of concrete increased as the amount of basalt fiber admixture increased. On the basis of 0.5% steel fiber admixture, the splitting tensile strength increased by 8% to 27% in comparison to the concrete without fiber admixture. As observed in Figure7(b), the splitting tensile strength exhibits a more pronounced increasing trend as the steel fiber admixture level rises. Based on 1.1 kg of basalt fiber admixture, the splitting tensile strength increases by 18%–64% when the steel fiber admixture level rises in comparison to the concrete without fiber. This indicates that the two types of fibers have different strengths and weaknesses of the effect on the splitting tensile strength of Lytag concrete, and the effect of steel fibers on the splitting tensile strength of concrete is more significant.

When the government investment entity is excluded from profit distribution, an additional dividend ratio is applied to social capital. Under unchanged conditions, the higher the additional dividend ratio, the greater the economic indicators for social capital. In the context of PPP projects, the government typically enhances project quality and increases the willingness of social capital to participate in bidding by ensuring that government investment entities do not share in profit distribution.

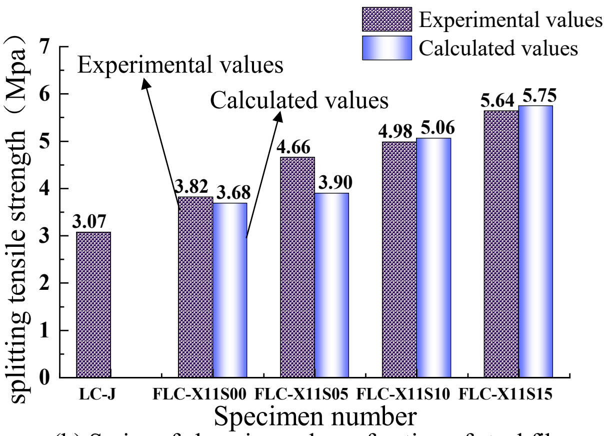
As demonstrated in (3), the formula for the splitting tensile strength of hybrid fiber reinforced Lytag concrete is derived from mathematical statistics based on the experimental data in this paper, considering that both steel and basalt fibers have some influence on tensile strength while also considering convergence and unity with the current specification.

$$f_{hzpt} = \alpha f_{t,0} + \beta_{ft} \lambda_f + \beta_{xt} m_x \quad (3)$$

f_{hzpt} is the splitting tensile strength of hybrid fiber reinforced Lytag concrete， $f_{t,0}$ is the splitting tensile strength of Lytag concrete without fiber, α is the splitting tensile strength adjustment coefficient （which can be taken as 1.15 according to this experiment），β_{ft} the steel fiber influence coefficient（according to this paper's experimental data to take 0.25），β_{xt} is the impact factor of the basalt fiber （according to this paper's experimental data to take 0.13）， m_x is the single party Lytag concrete basalt fiber mass admixture. According to (3) and the relevant parameters of this experiment, the experimental and calculated values of splitting tensile of hybrid fibers reinforced Lytag concrete are obtained and shown in Figure 7 which show good agreement between the two.



(a) Series of changing volume fraction of basalt fiber

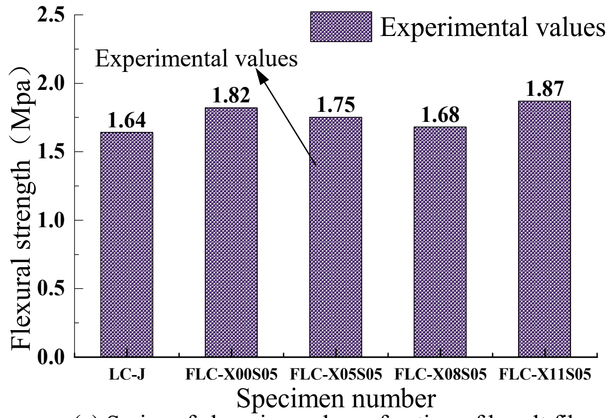


(b) Series of changing volume fraction of steel fiber

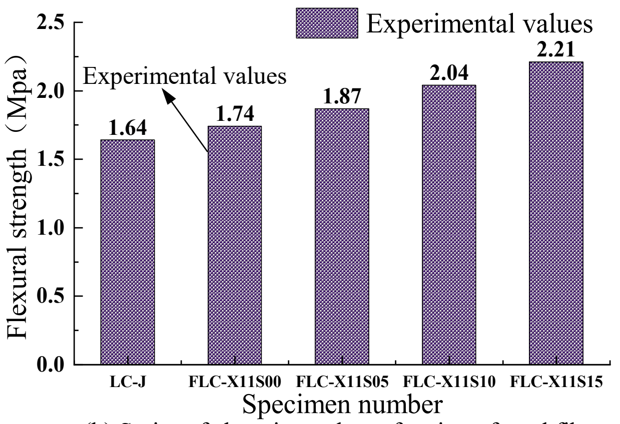
Fig.7. Experimental values and calculated values of splitting tensile strength

D. Analysis of flexural strength

The project also performed concrete flexural tests. Figure 8 depicts the change in flexural strength of hybrid fibers reinforced Lytag concrete under various single factor values. The figure clearly shows that changing the quantity of basalt fiber has minimal influence on flexural strength, however increasing the amount of steel fiber may greatly improve the flexural strength of Lytag concrete. However, earlier research has shown that basalt fiber can increase the flexural strength of concrete to some extent. The results of this experiment might be attributed to the small number of data samples and the discreteness of concrete, which could explain why basalt fiber had a lesser influence on flexural strength.



(a) Series of changing volume fraction of basalt fiber



(b) Series of changing volume fraction of steel fiber

Fig.8. Change rule of s flexural strength under single factor change

V. Early crack resistance and durability

A. Early crack resistance

The project team also carried out pertinent tests on the durability and early crack resistance of hybrid fibers reinforced Lytag concrete in accordance with the project plan. Due to the unique nature of the durability test, only four groups of mix proportions shown in TABLE V（Lytag concrete without fiber, steel fiber reinforced Lytag concrete, basalt fiber reinforced Lytag concrete, and hybrid fibers reinforced Lytag concrete）were tested for early crack resistance and durability. Early crack-resistant plate experiments were conducted using the Chinese standards "Standard for Long-term Performance and Durability Test Method of Ordinary Concrete" as a guide.

Each crack's average crack area:

$$a = \frac{1}{2N}\sum_{i=1}^{N}(W_i \times L_i) \tag{4}$$

The number of cracks per unit area:

$$b = \frac{N}{A} \tag{5}$$

Total cracking area per unit area:

$$c = a \times b \tag{6}$$

Where, W_i is the maximum width of the ith crack (mm); L_i is the length of the ith crack; N is the total number of cracks; A is the area of the plate(mm^2). Table VI show the results of the cracking test on the flat plate.From the results presented in the above table, it can be seen that both steel and basalt fibers were successful in improving the early cracking resistance of Lytag concrete and they were able to inhibit cracking by 16% to 28%. In addition, the addition of both steel and basalt fibers had a greater effect on the early cracking resistance, which suggests that hybrid fibers have a beneficial effect on the cracking resistance of Lytag concrete.

TABLE VI
Results of the Cracking Test on the Flat Plate

Specimen Number	FL-C	FLC-S	FLC-X	FLC-SX
Total Cracking Area per Unit Area (mm^2/m^2)	480	664.1	294.1	182

TABLE V
Design of the Concrete Mix Ratio

Specimen Number	Cement / kg·m^{-3}	Sand / kg·m^{-3}	Lytag / kg·m^{-3}	Sand Rate	Basalt Fiber / kg·m^{-3}	Steel Fiber / kg·m^{-3}
LC-J	480	664.1	294.1	39%	0	0
FLC-S	480	664.1	294.1	39%	0	39
FLC-X	480	664.1	294.1	39%	1.1	0
FLC-XS	480	664.1	294.1	39%	1.1	39

B. Seepage resistance

The seepage height method of the Chinese specification "Standard of Test Methods for Long-term Performance and Durability of Ordinary Concrete" was used in this project, which usually analyzes the permeability of concrete by calculating the average seepage height of concrete under constant water pressure. A set of six specimens in the shape of a circular table body were cured for an age of 28 days. After paraffin baking and sealing, the impermeability meter was placed in the mold. When water seepage occurs on the top surface of more than one specimen, the test should be stopped immediately and the time recorded. If there is no seepage, the test is completed. If no water seepage occurs, the test should be ended after. Remove the specimen, with the press will be the test block in the center of the symmetrical fracture into two halves, record the water marks, select the trapezoidal plate glass plate were measured in an aliquot of water seepage height of the measurement point. The average value of the water penetration height of all equal points as the water penetration height of the specimen, a group of specimen water penetration height is the average value of the water penetration height of the concrete specimen.

Figure 9 shows the test values of the infiltration height of each numbered specimen.

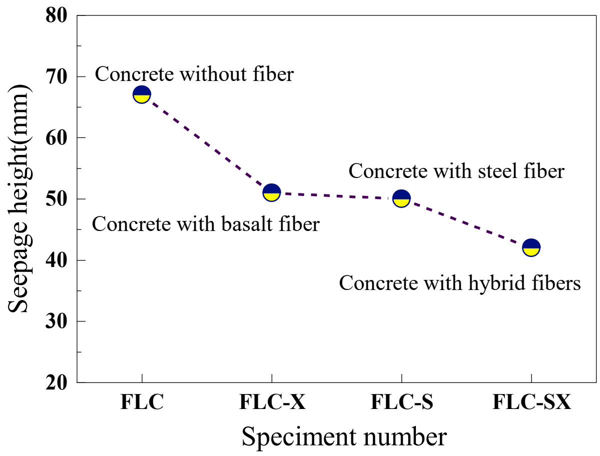


Fig.9. Seepage resistance

C. Creep of concrete

In this project, the creep experiment was also carried out on hybrid fibers reinforced Lytag concrete, and the specimens were made in accordance with Chinese standard. This project mainly analyzes the creep coefficient index. Due to the limitation of project time and other reasons, the duration of the creep test in this project is 180 days. The creep specimen is the same size as the self-shrinkage specimen, measuring 100*100*400mm cubic. The creep value is computed using the following formula:

$$\varepsilon_{ct} = \frac{\Delta L_t - \Delta L_0}{L_b} - \Delta\varepsilon_t \tag{7}$$

Where: ε_{ct} for the concrete creep value after t days of loading; ΔL_t for the total deformation after t days of loading (mm); ΔL_0 for the initial deformation of concrete at the beginning of loading (mm); L_b for the calibration distance (mm); $\Delta\varepsilon_t$ for the same age concrete shrinkage (need the same age specimens for shrinkage test).

The coefficient of concrete creep was calculated according to the following formula:

$$\varphi_t = \frac{\varepsilon_{ct}}{\varepsilon_0} \tag{8}$$

where ε_0 is the initial strain at the loading instant.

Figure 10 below shows the development of creep coefficient .

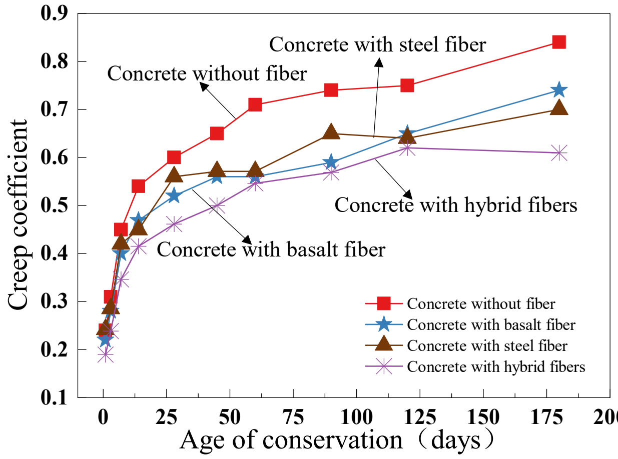


Fig.10. Law of development of the creepage coefficient

VI. CONCLUSION

This study demonstrates that the hybridization of steel fiber and basalt fiber in Lytag concrete achieves synergistic reinforcement through complementary mechanisms, effectively enhancing both mechanical and durability properties. The key findings are summarized as follows:

1.While the effect of fibers content on compressive strength is small, there is a clear phase change in the effect of hybrid fibers on tensile strength. Basalt fiber increase split tensile strength by 8-27%, while steel fiber increases it by 18-64%, suggesting that strengthening by interfacial bonding results in superior stress transfer. The change in flexural strength is less than 5% for basalt fiber and 22-35% for steel fiber.

2.According to the experimental data, through mathematical statistics and analytical calculations, this paper also proposes the formula for calculating the cubic compressive strength and splitting tensile strength of hybrid fibres reinforced Lytag concrete based on fiber characteristic parameters and the strength of vegan concrete, and the experimental values are in good agreement with the calculated values.

3.Incorporation of basalt and steel fibers significantly improves the early cracking resistance, permeability, and creep properties of Lytag concrete. Meanwhile, the hybrid fibers showed more superior results in mitigating early cracking, improving permeability, and controlling creep and deformation.

According to the experimental results of this study, hybrid fibers reinforced Lytag concrete shows significant improvement in both mechanical properties and durability, which proves its potential for wide application in construction engineering. However, certain limitations of this study must be recognized. Firstly, the number of parameters and levels in the orthogonal design is still insufficient, and secondly, the study is still at the material level, and the study of the properties of its structure has not yet been carried out. Future research could incorporate machine learning algorithms to model the quantitative relationship between fiber type, doping and mechanical properties to achieve multi-objective optimal design, as well as to carry out performance studies at the structural component level.

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