ISSN: 1813-4890

Experimental study on compressive performance of fiber-reinforced lightweight aggregate concrete after fire

Mingren Zhao, Yunlong Zhou

North China University of Science and Technology, College of Civil and Architectural Engineering, Hebei 063210, China

Abstract

To investigate the effect of fibers on the cube properties of lightweight aggregate concrete after high temperature fire, 15 sets of lightweight aggregate concrete standard cube specimens were prepared, each containing ceramic fibers, copper plated steel fibers, and ceramic copper plated steel fibers. The high-temperature fire test was conducted according to the international standard ISO834 heating curve. Analyzed the effects of different fiber types and dosages on the cracking behavior, mass loss rate, compressive strength, and residual compressive strength of lightweight aggregate concrete after 60 minutes of open flame high temperature. The experimental results showed that lightweight aggregate concrete with different ceramic fiber contents all experienced severe cracking, and copper plated steel fibers were superior to ceramic fibers in improving the anti cracking performance of lightweight aggregate concrete; After being exposed to fire for 60 minutes, the mass loss rate of lightweight aggregate concrete with the same copper plated steel fiber content decreases with the increase of ceramic fiber content, while the compressive strength and residual compressive strength rate increase.

Keywords

Lightweight aggregate concrete, compressive property, spallingy.

1. Introduction

With the increasing number of building fires, it seriously affects the safety of reinforced concrete structures. When concrete is subjected to high temperatures caused by fire, its mechanical properties decrease with increasing temperature due to changes in internal material properties. Lightweight aggregate concrete has the advantages of light weight, high strength, and good fire resistance. When producing and preparing lightweight aggregate concrete, industrial solid waste such as fly ash and silica fume are utilized, which is conducive to the comprehensive utilization of resources and energy conservation and emission reduction [1]. With the rapid development of the construction industry, lightweight aggregate concrete has been widely used in large-span bridges, high-rise buildings, tunnels and other engineering projects [2].

In recent years, studies have shown [3-5] that the high moisture absorption and low density of lightweight aggregate concrete have a significant impact on the high-temperature cracking of concrete. The residual compressive strength, flexural strength, and tensile strength after high temperature are lower than those of ordinary concrete. At present, many scholars have conducted extensive research on adding appropriate amounts of fibers to lightweight aggregate concrete to improve its mechanical properties, fire resistance, and high temperature resistance. Research has shown that an appropriate amount of inorganic fibers can form a mesh like spatial structure inside lightweight aggregate concrete, reduce the air content inside the concrete, and improve the compressive strength of the concrete [6]; Mixing steel fibers or hybrid fibers into

ISSN: 1813-4890

lightweight aggregate concrete effectively limits the development of cracks, enhances the ductility of concrete, and improves the mechanical properties of concrete after high temperature [7]. Copper plated steel fibers are high-strength and high elastic modulus steel fibers, and copper plating on the surface of steel fibers can effectively prevent rusting and expansion of steel fibers in concrete, effectively improving the compressive strength of concrete cubes [8-10]. Ceramic fiber is a new type of green and environmentally friendly inorganic fiber that has better bonding performance with concrete and is less likely to react with various additives in concrete.

By conducting open flame heating tests on lightweight aggregate concrete with different types and dosages of copper plated steel fibers, ceramic fibers, and ceramic copper plated steel fibers according to the international standard ISO834 heating curve, this study analyzes the effects of different fiber types and dosages on the cracking behavior, mass loss rate, compressive strength, and residual compressive strength of lightweight aggregate concrete at different fire times. This article aims to develop a fiber lightweight aggregate concrete that can be used for insulation and load-bearing systems of interior and exterior walls, providing a basis for optimizing the fire resistance design and post fire repair and reinforcement of fiber lightweight aggregate concrete.

2. Organization of the Text

2.1. Experimental materials

The experiment used Dunshi brand P · O42.5 ordinary Portland cement; The admixture uses Grade II fly ash with a loss on ignition of 6.5 and Grade II silica fume with a loss on ignition of 2.6; Fine aggregate is high-quality river sand with a fineness modulus of 2.76, belonging to Zone II medium sand; The coarse aggregate is 5-16mm fly ash ceramic particles, and the appearance is shown in Figure 1. The measured basic performance indicators are shown in Table 1; The fibers are made of copper plated steel fibers with good thermal conductivity and flame-retardant and fire-resistant ceramic fibers. The appearance shape is shown in Figure 2, and the performance indicators are shown in Table 2.

Tab. 1 Performance index of fly ash ceramsite

Particle size(mm)	Apparent density(kg/m^3)	Bulk density(kg/m^3)	1-hour water absorption rate(%)	Cylinder compression strength(MPa)
5-16	1612	1013	11.5	11

Tab. 2 Performance index of fibers

Fiber type	Fiber density(kg/m^3)	Fiber Length(mm)	Fiber diameter	Aspect ratio	Tensile strength(Mpa)
Copper plated steel fiber	7800	6	0.22mm	27.3	3000
Ceramic fiber	2600	6	3μm	2000	2400

2.2. Experimental mix ratio

The experiment considers the influence of different dosages of copper plated steel fibers and ceramic fibers on the compressive strength of fiber-reinforced lightweight aggregate concrete after high temperature fire. The benchmark mix is shown in Table 3, and the experimental grouping is shown in Table 4.

Fig.1 Fly ash ceramsite

(a)Copper plated steel fiber (b)Ceramic fiber
Fig.2 Fibers

Tab. 3 Mix proportion of lightweight aggregate concrete

Strength (kg/m^3)	Cement (kg/m^3)	Sand (kg/m^3)	Ceramsite (kg/m^3)	Fly ash (kg/m^3)	Silica fume (kg/m^3)	Water (kg/m^3)	Water reducing agent (kg/m^3)
C40	357	693	605	102	51	200	2.55

Tab. 4 Test grouping and results

Number	Copper plated steel fiber (kg/m^3)	Ceramic fiber (kg/m^3)	Mass loss (%)	Compressive strength (MPa)	Compressive strength after fire (MPa)	Residual rate of compressive strength (%)
60SF30CF0	30	0	24.6	45.5	7.2	15.8
60SF40CF0	40	0	24.0	46.1	7.6	16.5
60SF50CF0	50	0	24.2	47.2	7.9	16.7
60SF0CF13	0	1.3	-	37.2	-	-
60SF0CF26	0	2.6	-	36.4	-	-
60SF0CF39	0	3.9	-	34.7	-	-
60SF30CF13	30	1.3	26.7	39.0	6.4	16.4
60SF30CF26	30	2.6	26.1	38.0	6.5	17.1
60SF30CF39	30	3.9	21.5	37.7	6.7	17.8
60SF40CF13	40	1.3	26.3	40.8	6.8	16.7
60SF40CF26	40	2.6	24.6	40.5	6.8	16.8
60SF40CF39	40	3.9	12	39.0	7.1	18.2
60SF50CF13	50	1.3	25.3	42.5	7.2	16.9
60SF50CF26	50	2.6	25.3	40.9	7.2	17.6
60SF50CF39	50	3.9	10.3	40.8	8.0	19.6

2.3. Experimental scheme

In this experiment, 15 sets of 100mm × 100mm × 100mm cubic specimens with different fiber types and fiber contents were made, and the compressive strength test of the cubes was conducted after 60 minutes of fire exposure. In order to ensure the quality of concrete mixing, the ceramic fibers are dispersed with polyacrylamide (PAM) before mixing, and the fly ash ceramic particles are wetted with water. After 28 days of standard maintenance conditions, place it in a dry and ventilated place for 2-3 days, and conduct a fire test after natural drying. The experiment used a 3600mm × 6000mm × 1760mm horizontal furnace in the Fire Laboratory of North China University of Science and Technology, and conducted fire temperature rise experiments according to the international standard ISO834 temperature rise curve. After heating for the predetermined time, stop heating and cool down naturally to room temperature. Open the furnace cover, observe the bursting of the test block, measure the mass loss and residual compressive strength of the test block.

3. Test results and Analysis

3.1. Experimental phenomenon

There are significant differences in the number and condition of explosions of different fiber types of test blocks under different fire exposure times after high temperature, as shown in Table 5 for specific statistics.After being exposed to fire for 60 minutes, the concrete test block experienced severe cracking. The serious cracking of ceramic fiber lightweight aggregate concrete is mainly due to the fact that ceramic fibers are flame-retardant materials that do not melt after being exposed to fire, and have a good bond with concrete aggregates, resulting in a large temperature difference between the inside and outside. After being exposed to fire for 60 minutes, the surface of the test block is covered with powdery particles, and the crack width increases. As the fire exposure time increases, the concrete test block changes from dark gray to gray white. After adding ceramic copper plated steel fiber lightweight aggregate concrete, large cracks and numerous small holes appeared around it after 60 minutes of fire, and some test blocks experienced corner cracking.

Tab. 5 Burst characteristics of fiber reinforced lightweight aggregate concrete after fire

Fire exposure time	Fiber type	Number of test blocks	Remaining complete quantity	Number and situation of explosions
60min	Ceramic fiber	18	0	9 Corner explosion 9 Splitting and bursting
	Copper plated steel fiber	18	18	None
	Ceramic Copper Plated Steel Fiber	54	36	9 Corner explosion 9 Splitting and bursting

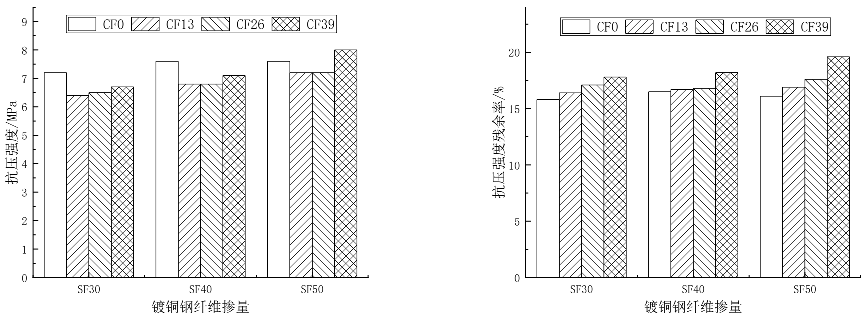
Through analysis, it can be concluded that under the high temperature of an open flame, the surface of a single ceramic fiber lightweight aggregate concrete specimen expands due to heat. Due to the low thermal conductivity of ceramic fibers, there is a significant temperature gradient between the interior and exterior of the specimen; At the same time, the cementitious material continues to deteriorate due to prolonged exposure to high temperatures. Due to the combined effects of internal vapor pressure and temperature stress, when the stress reaches the tensile strength of the concrete itself, cracks appear in the test block. Under high temperature, the cracks rapidly develop and cause bursting. Single copper plated steel fiber lightweight aggregate concrete, due to its good thermal conductivity, can alleviate the temperature gradient inside and outside the test block, reduce temperature stress. At the same time, copper plated steel fiber can effectively tie the concrete on both sides of the crack, improve the tensile strength of the concrete after cracking, and reduce the cracking phenomenon of concrete under the combined action of temperature stress and steam pressure.

3.2. Residual compressive strength after fire

The decrease in compressive strength of fiber-reinforced lightweight aggregate concrete after fire is mainly due to the complex physical and chemical changes that occur inside the test block after the high temperature of the fire, resulting in structural damage to the internal structure of lightweight aggregate concrete. Under the fire, the free water and crystalline water in the test block gradually evaporate, as well as the dehydration and evaporation of cementitious structures such as C-H and C-S-H, exacerbating the damage to the internal structure and causing a further decrease in compressive strength.

From Figure 3 (a), it can be seen that the compressive strength of ceramic fibers mixed with 1.3kg/m3, 2.6kg/m3, and 3.9kg/m3 of lightweight aggregate concrete with copper plated steel fiber content of 30kg/m ^{3} and 40kg/m ^{3} after 60 minutes of fire is lower than that of lightweight aggregate concrete with copper plated steel fiber content alone; When the content of copper plated steel fibers remains constant, the compressive strength gradually increases with the increase of ceramic fiber content after fire; The compressive strength of lightweight aggregate concrete with a copper plated steel fiber content of 50kg/m ^{3} and a ceramic fiber content of 3.9kg/m ^{3} is higher than that of lightweight aggregate concrete with a single copper plated steel fiber content.

According to Figure 3 (b), it can be seen that the residual compressive strength of ceramic fibers mixed with 1.3kg/m3, 2.6kg/m3, and 3.9kg/m3 copper plated steel fiber lightweight aggregate concrete after 60 minutes of fire is higher than that of single copper plated steel fiber lightweight aggregate concrete. With the increase of ceramic fiber content, the residual compressive strength gradually increases; Among them, the residual rate of compressive strength of lightweight aggregate concrete mixed with 1.3kg/m3, 2.6kg/m3, and 3.9kg/m3 ceramic fibers with a copper plated steel fiber content of 50kg/m ^{3} showed the best improvement effect, increasing by 0.2%, 0.9%, and 2.9% respectively.



(a)compressive strength (b)Residual compressive strength

Fig.10 Compressive strength and residual rate of ceramic copper plated steel fiber concrete exposed to fire for 60min

3.3. Quality loss rate after fire

Under the high temperature of fire, the moisture in lightweight aggregate concrete gradually evaporates, and the cementitious structures such as C-H and C-S-H gradually hydrate and decompose, which can cause quality loss of lightweight aggregate concrete. The quality loss rate can indirectly reflect the variation law of compressive strength and internal damage of lightweight aggregate concrete.

From Figure 4, it can be seen that after being exposed to fire for 60 minutes, different ceramic copper plated steel fiber mixing methods have different effects on the quality loss rate of lightweight aggregate concrete. When the content of copper plated steel fibers remains constant, the quality loss rate of lightweight aggregate concrete gradually decreases with the increase of ceramic fiber content. The mixing effect of ceramic fiber content of 3.9kg/m ^{3} and copper plated steel fiber content of 40kg/m ^{3} and 50kg/m ^{3} is the best, with a quality loss rate of only 12% and 10.3%, respectively.

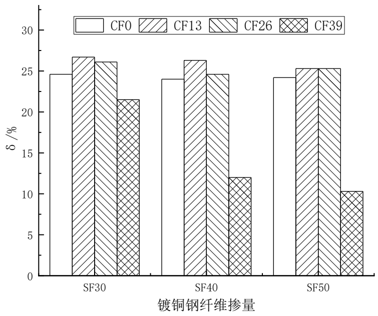


Fig.4 Mass loss rate of ceramic copper plated steel fiber lightweight aggregate concrete after 60 minutes of fir

4. Conclusion

1) With the increase of fire exposure time, severe cracking occurred in ceramic fiber lightweight aggregate concrete with different dosages; The concrete mixed with steel fiber lightweight aggregate did not experience cracking, while the concrete mixed with ceramic copper plated steel fiber lightweight aggregate experienced corner cracking; In terms of improving the anti explosion performance of lightweight aggregate concrete, copper plated steel fibers are superior to ceramic fibers and ceramic copper plated steel fibers.

2) Lightweight aggregate concrete with the same fire exposure time (60 minutes) and the same dosage of copper plated steel fibers shows a gradual decrease in mass loss rate with the increase of ceramic fiber dosage, while compressive strength and residual compressive strength gradually increase.

3) After being exposed to fire for 60 minutes, the mixing effect of ceramic fiber with a dosage of 3.9kg/m ^{3} and copper plated steel fiber with a dosage of 50kg/m ^{3} was the best, with a mass loss rate of only 10.3%. Compared with the residual compressive strength of lightweight aggregate concrete with a single dosage of 50kg/m ^{3} of copper plated steel fiber, the residual compressive strength increased by 2.9%.

Acknowledgements

This research was supported by College Student Innovation and Entrepreneurship Training Program Project.Project number: X2024164.

References

[1] Li J J, Wan C J, Niu J G, et al. Investigation on flexural toughness evaluation method of steel fiber reinforced lightweight aggregate concrete[J]. Construction and Building Materials, 131 (2017) 449-458.

[2] CUI H Z, LO T Y, MEMON SA, et al. Effect of lightweight aggregates on the mechanical properties and brittleness of lightweight aggregate concrete[J]. Construction and Building Materials， 2012, 35: 149-58.

[3] Domagala, Lucyna. Modification of properties of structural lightweight concrete with steel fibres[J]. Journal of Civil Engineering and Management, 2011, 17(1): 36-44.

[4] LIU X, WU T, YANG X. Properties of self-compacting lightweight concrete reinforced with steel and polypropylene fibers[J]. Construction and Building Materials, 226 (2019): 388–398.

[5] Kiran T, Yadav SK , Anand N, et al. Performance evaluation of lightweight insulating plaster for enhancing the fire endurance of high strength structural concrete[J]. Journal of Building Engineering, 57 (2022): 104902.

[6] Saif K, Zaid Al-Azzawi, Khalid B. Effect of discarded steel fibers on impact resistance, flexural toughness and fracture energy of high-strength self-compacting concrete exposed to elevated temperatures[J]. Fire Safety Journal, 121 (2021): 103271.

[7] Aref A, Husain A, Abdulrahman Al, et al. Effectiveness of GFRP strengthening of normal and high strength fiber reinforced concrete after exposure to heating and cooling[J]. Engineering Science and Technology, 36 (2022): 101147.

[8] RIZALMAN A N, MAHMOOD Y S N T M, Shahrin M .Parametric Study of Fire Performance of Concrete Filled Hollow Steel Section Columns with Circular and Square Cross-Section[J]. E3S Web of Conferences, 2018, 3401011.

[9] N. GANESAN, P.V， INDIRA, M.V, SABEENA. Bond stress slip response of bars embedded in hybrid fibre reinforced high performance concrete[J]. Construction and Building Materials, 2014, 50(50).

[10] LIMIN L, WEIHAO X, SHAOHUA W, et al. Bond Property between Rebars and Basalt Fiber–Reinforced Concrete after Exposure to High Temperatures[J]. Journal of Materials in Civil Engineering, 2023, 35(10).