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A review of the mechanical properties of fiber concrete after fire

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Abstract

The hybrid fiber high performance lightweight aggregate concrete pipe sheet has the advantages of light weight, suitability, durability, workability, strength, toughness and economy. The steel fibers in the hybrid fibers can replace the steel reinforcement and optimize the configuration of shear and flexural reinforcement, which can improve the mechanical properties of the pipe sheet. Under the high temperature of fire, steel fiber can effectively improve the mechanical properties of light aggregate concrete such as flexural strength and toughness, while polypropylene fiber has a low melting point to prevent concrete from bursting, making full use of the two different fibers to play their respective advantages. This paper is mainly from the fiber mixing, type and fire performance after the summary of the relevant summaries and recommendations for the research direction.

Keywords

High performance concrete; steel fibers; high temperature; post-fire.

1. Introduction

Fire is a serious hazard for concrete structures. Lightweight Aggregate Concrete is known for its lightweight, fire resistant and high strength benefits. Lightweight aggregate concrete (LWC) has advantages such as better fire resistance and durability compared to normal weight aggregate concrete (NWC). Many studies have shown that the use of fibers in lightweight aggregate concrete can be a way to improve mechanical properties. In fiber-reinforced concrete, fibers can prevent bursting, can dissipate local internal stresses, cut off cracks due to internal stresses and the expansion path of the original cracks, and prevent plastic drying cracks from occurring during the initial setting process of concrete.

Fire will directly lead to bursting and mechanical properties of concrete components to reduce the serious damage to the concrete structure, reduce the bearing capacity of concrete components and durability and other hazards. High-performance concrete (HPC) is a concrete mixture with advantages such as high ease of use and high strength. Although HPC outperforms normal strength concrete in almost all performance criteria, it also shows a higher tendency for thermally induced concrete spalling when exposed to severe heating or fire [1]. High-performance lightweight aggregate concrete has the advantages of lightweight, fire-resistant, and durable [2], and the inclusion of hybrid fibers in high-performance lightweight aggregate concrete, steel fibers effectively enhance the mechanical properties of high-performance lightweight aggregate concrete such as flexural strength, residual strength after high temperature, and toughness, and polypropylene fibers can prevent concrete from bursting. At present, the research on the performance of high performance lightweight aggregate concrete pipe sheet after high temperature with mixed fibers is less, and mainly focuses on the material properties test.

2. Study of the effect of different fiber types on the properties of concrete materials at high temperatures

It is well known that Lightweight Aggregate Concrete (LWC) is more advantageous than Normal Weight Concrete (NWC) because it reduces the deadweight of the structure, better insulation of the building as well as lower transportation costs, reduces the possibility of concrete spalling, Lightweight Aggregate Concrete is a sustainable and green building material [3].

Omar A. Abdulkareem et al [4] investigated the mechanical and microstructural properties of lightweight aggregate geopolymer concrete (LWAGC) before and after exposure to high temperatures ranging from 100 to 800°C. The experimental results showed that the compressive strength of concrete remains almost unchanged when LWAGC is exposed to high temperatures of 100, 200, and 300°C, respectively, but the compressive strength of LWAGC decreases dramatically when exposed to temperatures of 400-800°C, the compressive strength of concrete decreases sharply.

Cristian [5] conducted an experimental study on the effect of PP fiber type and dosage on the thermally induced spalling tendency of concrete, and the experimental results showed that smaller cross-section PP fibers had a positive effect on reducing the spalling tendency, and longer PP fibers appeared to be more effective in reducing the spalling tendency. It was also noted that the addition of PP fibers had a significant negative effect on the slump value.

Zhang et al [6] investigated the effect of flax fibers and steel fibers on the spalling behavior and compressive strength of Ultra High Performance Concrete (UHPC) after exposure to elevated temperatures. The combined use of steel and flax fibers completely prevented spalling of UHPC with relatively low fiber content, and the use of steel or flax fibers alone did not prevent spalling even at high fiber content. The effect of this synergistic blend of flax and steel fibers on improving UHPC spalling resistance is attributed to the increased permeability of the flax fibers and the bridging effect of the steel fibers at elevated temperatures.

Mugume Rodgers Bangi [7] used different lengths and diameters of polypropylene, polyvinyl alcohol and steel fibers exposed to high temperatures in fiber-reinforced high-strength concrete (HSC) on the effect of maximum pore pressure measured at different depths. The results of the tests showed that polypropylene fibers were more effective in reducing the maximum pore pressure compared to polyvinyl alcohol fibers, while steel fibers had a slightly lower effect. Longer organic fibers with a length of 12 mm and a smaller diameter of 18 μm showed better performance than shorter and larger diameters of 28 and 40 μm with a length of 6 mm.

RamoelSerafinia et al [8] investigated the effect of high temperature on the performance of steel fiber bond slip at the end of the hooks and showed that the contribution of the end hooks decreases with increasing temperature and is negligible for temperatures higher than 600°C, the bond strength increases significantly at 450°C and decreases sharply at temperatures of 600 and 750°C.

HabibAkbarzadeh Bengar et al [9] investigated the effect of temperature (five temperatures), steel fiber volume ratio (three volume ratios) and the thickness of the protective layer on the compressive strength and the bond properties of the reinforcement and the results of the tests showed that with the increase in the volume ratio of steel fibers, the concrete and reinforcement bond strength increased, and at higher temperatures, the fibers increased the concrete cover of all the The bond strength of the ordinary specimen with 65 mm of protective layer was 4.85 MPa at 600°C, and the addition of 1% fiber increased the bond strength by 45.1% to 7.04 MPa.

The ability of lightweight aggregates to act as a reservoir for evaporated water, ceramic granules can be incorporated into concrete as an internal curing material [16] to improve the mechanical properties of concrete; lightweight aggregate concrete shows high residual compressive strength after exposure to elevated temperatures [17,18]. Qianmin Ma et al [19] tested the spalling and mechanical properties of modified vitrified concrete specimens at room temperature and after exposure to elevated temperatures (200 to 1200°C), and the test results showed that modified vitrified concrete still has considerable residual mechanical properties after exposure to 1200°C. The gradual decomposition of the polymer used as a modifying material with increasing temperature can create vapor release channels and reduce the possibility of concrete spalling.

Jiang Yuchuan et al [20] studied the bursting of shale vitrified concrete after high temperatures with different mixing ratios, and the test results showed that the high-temperature bursting rate was related to the wet content of shale vitrified concrete; no bursting occurred in the shale vitrified concrete after mixing with reticulate polypropylene fibers.

Different cooling methods affect the strength of lightweight aggregate concrete. Lin Xinyan et al [21] test showed that: water injection cooling is more crumbly, aggregates are more likely to fall off, and the splitting tensile strength of the concrete after high temperature decays faster than the compressive strength; Guo Rongxin et al [22] experimental study found that, after high temperature concrete specimens after the resting time of 1d, the natural cooling method is higher than the compressive strength of the water injection cooling; when resting for 14, 28d, the temperature of 500 ℃ and 700 ℃ after the action of the water injection cooling specimens were higher than the natural cooling specimens.

Zhu De et al [23] conducted an experimental study on the thermal conductivity and thermal conductivity of SFRC after high temperature. The test results showed that the thermal conductivity coefficient of SFRC at 300°C showed an inflection point and an increasing trend; meanwhile, at the same temperature, the thermal conductivity coefficient and the thermal conductivity coefficient showed an increasing trend with the increase of the steel fiber content.

The addition of polypropylene (PP) fibers to concrete mixtures reduces the tendency of thermally induced concrete spalling [24,25, 26,44]. Polypropylene fibers at a dosage of 0.1% can function at temperatures up to 800°C because the polypropylene fibers melt leaving voids to release steam. Because polypropylene fibers melt leaving voids to release vapors, PP fibers melt around 170°C, and spalling of concrete that typically occurs at 190 to 250°C, organic fibers that melt before or near the lower end of the spalling temperature range may be more effective in mitigating pressure rise and therefore the potential for concrete spalling because they will provide earlier relief from pressure rise. The PP fibers will improve the post-temperature strength of concrete as they effectively release the internal vapor pressure of the matrix and prevent the concrete from bursting at high temperatures.

Guo Jiadong [24] studied the mechanical properties of lightweight aggregate concrete with polypropylene fibers after high temperature, and the results showed that lightweight aggregate concrete with polypropylene fibers can inhibit lightweight aggregate concrete bursting and improve ductility.

Chen Bing et al [26] conducted an experimental study on the residual strength of high-strength concrete (HSC) and hybrid fiber-reinforced high-strength concrete (HFRHSC) after exposure to elevated temperatures, and the results showed that the first spalling of HSC reinforced with high-melting-point fibers occurs when the temperature reaches about 800°C, while HSC reinforced with low-melting-point polypropylene (PP) fibers did not spall at elevated temperatures. Blending high melting point fibers (carbon or steel fibers) with low melting point fibers (PP fibers) HSC can greatly improve the performance of HSC after exposure to high temperatures.

Guo Xinjun [28] and Luo Junli [29] et al. conducted fire high temperature tests on lined concrete materials and components. The results showed that polypropylene fibers reduced the high temperature bursting of lining concrete, while it was pointed out that the impermeability of polypropylene fiber concrete decreases after high temperature.

The high modulus of elasticity of steel fibers, in the lightweight aggregate concrete mixed with steel fibers can effectively improve the tensile strength, flexural and other mechanical properties [30-33], related research pointed out that steel fiber concrete after high temperature can effectively improve the compressive strength of concrete, the test proved that the mechanical properties of steel fiber concrete after high temperature are better than ordinary concrete [34,35]. Wang Huailiang et al [12] studied the fracture energy of steel fiber lightweight aggregate concrete after high temperature, and the experimental study showed that: the incorporation of steel fibers can effectively slow down the formation and expansion of cracks, thus improving the fracture energy. However, after the action of 600°C, the fracture energy showed a decrease.

The experimental study by Chao-Wei Tang [36] showed that the residual mechanical properties of lightweight aggregate concrete (LWC) after exposure of steel fibers to high temperatures were significantly improved. The residual mechanical properties of hybrid fiber-reinforced LWC were the best among the tested mixtures compared to fiber-reinforced LWC alone.

Danying Gao et al [37] investigated the effects of steel fiber type, fiber volume fraction and water-cement ratio on the tensile properties of steel fiber reinforced mortar (FRM) exposed to high temperatures. The results showed that the tensile strength, modulus of elasticity and Poisson's ratio of FRM gradually decreased with the increase of exposure temperature. At higher temperatures, the effect of hooked ends and corrugated fibers on the tensile behavior of FRM was more significant than that of straight fibers.

Dengxin Yu et al [38] investigated the compressive strength of steel fiber lightweight aggregate concrete at different temperatures, and the test results showed that the compressive strength of steel fiber lightweight aggregate concrete first increased and then decreased the trend with temperature, and the residual compressive strength after different high temperatures was higher than that of ordinary lightweight aggregate concrete.

Chen Bing et al [26] conducted an experimental study on the residual strength of high-strength concrete (HSC) and hybrid fiber-reinforced high-strength concrete (HFRHSC) after exposure to elevated temperatures, and the results showed that mixing high-melting-point fibers with low-melting-point fibers of HSC can greatly improve the performance of HSC after exposure to elevated temperatures.

Gao Danying et al [39] and Yanlan et al [40] studied the high temperature performance of hybrid fiber HSC, and the test results showed that the hybrid fiber effectively inhibited the high temperature bursting of HSC after mixing with hybrid fiber.

Yang Juan [41] on the 7.5 ℃ / min and 2.5 ℃ / min two kinds of heating rate on the high-temperature bursting of ultra-high performance concrete, the test results show that the heating rate of different effects of ultra-high performance concrete high-temperature bursting of different degrees, the greater the heating rate, the more serious the high-temperature bursting.

Qian Yunfeng [42] studied the effect of fiber (no fiber, single mixed steel fiber, mixed with steel fiber and synthetic fiber) on the high-temperature performance of ultra-high performance concrete, with the increase in temperature, the residual compressive strength of ultra-high performance concrete showed a trend of increasing and then decreasing; mixing of steel fibers can inhibit the development of cracks, mixed with steel fibers and synthetic fibers can effectively improve the behavior of high temperature bursting of ultra-high performance concrete.

Wang Huailiang et al [43] studied the fracture energy of steel fiber and PP fiber lightweight aggregate concrete before and after high temperature, and the results showed that the admixture of 1% volume of steel fibers effectively slowed down the formation and expansion

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of cracks, and improved the ductility of lightweight aggregate concrete. Within the temperature of 25~400℃, the fracture energy of concrete specimens increased gradually with the rise of temperature, and after the action of 600℃, the fracture energy showed a decrease phenomenon.

3. Study of the effect of different fiber types on the performance of concrete elements at elevated temperatures

Concrete structures under the action of high temperature will produce bursting phenomenon, which will lead to the loss of structural bearing capacity. Currently, there are three main theories for high-temperature bursting of concrete: vapor pressure mechanism, thermal stress mechanism, and thermal cracking mechanism [44]. Concrete exhibits a reduction in compressive and flexural strength, loss of bond between aggregate and cement paste, deterioration of the hardened cement paste and in some cases spalling. The addition of fibers (especially polypropylene fibers) reduces the chances of concrete spalling while coarse fibers (e.g., steel, polypropylene) ensure the residual load carrying capacity of the structure [30].

M. Shariq et al [10] studied the bending tests of normal and high strength reinforced concrete (RC) beams with and without convoluted steel fibers after exposure to elevated temperatures. The test results showed that the addition of fibers to RC beams produces ductile damage and delays the onset of flexural and shear cracks, and that the ultimate load carrying capacity of high-strength RC beams with steel fibers is higher than that of high-strength RC beams without steel fibers after exposure to temperatures of 200°C.

KhalilSijavandi et al [11] investigated the effect of replacing high strength steel (HSS) and glass fiber reinforced polymer reinforcement (GFRP) reinforced hybrid concrete beams made of conventional concrete with high performance fiber reinforced cementitious composites (HPFRCC), the experimental results showed that the HPFRCC beams in terms of their load carrying capacity, flexural strength, flexural stiffness exhibited improvement, ductility and energy absorption compared to similar conventional concrete beams. In addition, the more the effective reinforcement ratio of single and mixed reinforcement was increased in the hybrid beams, the ductility was improved by 37% to 88% compared to the reinforced concrete beams cast with HPFRCC.

Mohammed Munqith Salman et al [12] investigated the effect of polypropylene fibers (PPM-12) and Nitinol (NiTi) superelastic shape memory alloy (SMA) wires on concrete beams subjected to repeated bending loads, and the experimental results showed that the addition of PPM-12 fibers to the concrete had a negative impact on the mechanical properties of the concrete, and that the addition of the fibers resulted in the crack expansion in the concrete was controlled and increased the fatigue life of the concrete. (NiTi) superelastic threads were active in some samples and could be displaced with some recovery. Polypropylene fibers and NiTi wires were used as reinforcement to increase the life of the concrete and to reduce crack propagation in the concrete.

Milad Adnan Hadi [13] studied the reinforcement of beams to avoid sudden damage (torque-bending) by adding steel fibers and the test results showed that hooked steel fibers were more effective in increasing the strength to resist the combined forces of bending and torque. The fibers significantly improved the overall structural performance of reinforced concrete beams while increasing the ductility of the concrete and the stiffness of the beams.

Srishti Banerji et al [14] conducted an experimental study of Ultra High Performance Fiber Reinforced Concrete (UHPFRC) beams under the action of fire, the results of which showed that UHPFRC beams are highly susceptible to explosive spalling in the compression zone (lateral) of the beam cross section resulting in low fire resistance. When polypropylene fibers are present in UHPFRC, the level of fire-induced spalling is reduced, improving the fire resistance. Also higher loading levels help to release pore pressure through tensile cracking and reduce the degree of spalling of UHPFRC beams.

Perry Adebar et al [15] investigated the shear tests of hoopless fiber concrete beams and the results showed that increasing the fiber content reduced the crack width and increased the shear strength, with a maximum shear strength increase of 117%. 50mm long fibers produced a similar shear strength to the same volume of 30mm long fibers but with much higher ductility.

Cong Zhang [45] showed that blended fibers (steel fibers and fine PP fibers) had the best effect on the reduction of steam pressure inside the SCC, while pointing out that the effect of the geometry of the PP fibers should not be ignored.

Liang Yu [46] investigated the shear performance of HyFRSCC tilting beams after high temperature, and the test results showed that the admixture of steel fibers increased the residual load carrying capacity of HyFRSCC tilting beams, and it was also concluded that the polypropylene fibers melted at high temperatures to produce a large number of cracks and holes in HyFRSCC tilting beams, which resulted in the blended-fiber concrete being less than the load carrying capacity of the single-admixed steel-fiber concrete beams.

Cong Zhang et al [47] investigated the effect of steel fibers, structural PP fibers, and fine PP fibers on the residual bearing capacity of self-compacting concrete simply supported beams after high temperature action, and the test results showed that the fibers effectively improved the bearing capacity of self-compacting concrete beams after high temperature, and the structural PP fibers and fine PP fibers, and steel fibers increased the bearing capacity of self-compacting concrete beams after high temperature more than the structural PP fibers and fine PP fibers. more obvious.

You Zhiguo et al [48] investigated the effect of concentrated load on the damage pattern of self-compacting concrete beams when steel fibers replaced the hoop reinforcement, and the test results showed that the damage pattern of beams could be changed from brittle to ductile when steel fiber mixing and hoop reinforcement were at a certain content, and steel fibers could partially replace the hoop reinforcement.

Ji Yao [49] studied the light aggregate steel pipe concrete columns after fire by test, the test results show that: light aggregate steel pipe concrete columns and the axial compression damage morphology after fire at room temperature is almost the same; steel fiber doping will increase with the temperature, the effect of the increase in the bearing capacity of the light aggregate steel pipe concrete columns after the fire and reduce.

Yan Zhiguo et al [50] conducted an experimental study on steel fiber concrete pipe sheet after fire, and the test results showed that: and ordinary reinforced concrete pipe sheet with the maximum temperature is the opposite relationship; the maximum temperature on the steel fiber concrete pipe sheet has a relatively small effect.

Li Xiaoke et al [51] studied the flexural performance of steel fiber composite recycled aggregate concrete (SFR-CRAC) beams with 500 MPa longitudinal steel reinforcement, the test results show that the steel fibers enhance the crack resistance of SFR-CRAC beams and the tensile strength of the SFR-CRAC, the use of reasonable longitudinal reinforcement rate design of the steel reinforcement SFR-CRAC beams in the 500 MPa longitudinal steel bar Failure in the typical mode of rapid expansion of major cracks after yielding and crushing of SFR-CRAC in the compression zone.

Jin Liu et al [52] investigated four steel fiber concrete (SFRC) beams tested after pre-impact loading (impact velocity = 5.4 m/s) to observe their fire resistance, and the test results showed that the damage mode of SFRC under low-velocity impact loading changed from shear to flexural as the amount of steel fibers increased. When the impact energy was low, the beams were still in the elastic phase and showed good fire resistance, although they were weakened by pre-impact. It is also noted that limited to low energy impact conditions, the effect of steel fiber content on the thermodynamic behavior of damaged beams is negligible.

4. Conclusion

At present, there are fewer studies on the high temperature performance of mixed-fiber high-performance lightweight aggregate concrete pipe sheet, and they are mainly focused on material properties test. There have been studies on the high temperature before and after the hybrid concrete beam components are only ordinary concrete or high performance concrete beam high temperature performance research, mixed fiber high performance lightweight aggregate concrete pipe sheet high temperature performance research is very little.

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