A Review of fatigue performance of fiber mixture with concrete

Abstract: The fatigue performance of fiber reinforced concrete is a research hotspot in the field of civil engineering. This paper systematically reviews the related research.The fatigue performance of fiber reinforced concrete is different from that of ordinary concrete because the internal structure is changed by the addition of fiber.Different kinds of fibers have different effects on fatigue performance.Steel fiber can enhance the toughness of the matrix, effectively hinder crack propagation, and significantly improve the fatigue life.Synthetic fibers have obvious effects in inhibiting early microcracks, and the mixed use of the two will produce complementary phenomena.Among them,steel fiber has the greatest improvement in the mechanical properties of concrete,with an average increase of 30.5%-41.7%.Glass fiber and synthetic fiber have improved the mechanical properties of concrete,with an increase of 10.5%-14.6%.Among them, the improvement of mixed fiber is significantly higher than that of single fiber,and the mechanical properties are improved by about 45%-59.2%.The existing research mostly focuses on experimental analysis, numerical simulation is relatively less, and the research on long-term fatigue performance in practical engineering applications is still insufficient.In the future, it is necessary to strengthen multi-scale research, improve numerical models, and deeply explore its fatigue behavior in complex environments, so as to provide more solid theoretical support for engineering applications.

Keywords: Mixed fiber, fiber reinforced concrete, fatigue performance, Synthetic fibers

Introduction

In recent years, the excellent crack resistance and impact resistance of fiber reinforced concrete have made it widely used in bridge deck pavement, airport runway, railway sleeper, shield segment, civil building floor and prefabricated parts with complex stress distribution, fatigue resistance and impact resistance. However,due to long-term exposure to various vehicle loads, seismic loads, freeze-thaw cycles and other influencing factors, fiber reinforced concrete is also vulnerable to fatigue damage. Fatigue load[1] will cause these structures to crack in advance and lose mechanical properties. Therefore, it is very important to study the fatigue characteristics of fiber reinforced concrete to ensure the safety and reliability of the structure.

Study on fatigue performance of single fiber concrete

Steel fiber reinforced concrete (SFRC) has excellent mechanical properties such as tensile strength, crack resistance, fatigue resistance and impact resistance. It is characterized by 'cracking' but not crushing. Studying the fatigue characteristics of SFRC can help us understand its crack propagation and fatigue life under cyclic loading, and provide a basis for engineering design and construction. The stress level[2],cyclic load frequency, fiber type and length, concrete strength grade and other factors will affect the fatigue life of SFRC. Zhang Zhibiao et al.[3] studied the uniaxial fatigue test of SFRC specimens with 4 kinds of steel fiber volume content and 8 stress levels by electro-hydraulic servo material testing machine. It was found that with the increase of steel fiber content, the fatigue strength also increased, but when the fiber content exceeded 1.0 %,the strength increase decreased. This shows that although the increase of fiber content has improved the fatigue strength of concrete, when it exceeds a certain limit,the enhancement effect will become smaller and smaller,and within a reasonable range of content, the fatigue performance of concrete has a higher improvement.Gao Danying et al.[4]studied the effects of different steel fiber volume ratios,steel fiber types and steel fiber thickness on the fatigue of steel fiber reinforced high-strength concrete beams. The variation law of crack width of steel fiber reinforced concrete beams under fatigue load was obtained and the crack calculation formula was summarized.The results show that the addition of steel fiber in concrete can improve the fatigue performance and crack resistance of concrete beams, and can reduce the cracks caused by fatigue load.Mei Yingjun et al.[5] obtained the bending fatigue life of ordinary concrete and steel fiber polymer concrete at 90 days of different stress levels through three-point bending fatigue test,and analyzed its influence on the fatigue performance of concrete by studying its pore structure characteristics. It is concluded that the fatigue life of steel fiber polymer concrete obeys Weibull distribution under the same stress level, and the fatigue life is much higher than that of ordinary concrete. The double logarithmic fatigue equation of concrete with failure probability of 0.5 is established. After adding steel fiber, the harmful pores of concrete are reduced and the harmless pores are increased, thereby improving the fracture strength under fatigue load.This fully shows that the incorporation of steel fibers in concrete will dissipate a certain amount of damage energy when it is subjected to fatigue load,which improves the fatigue life of concrete.Feng Zhongren et al.[6] studied the fatigue life of concrete beams with three different steel fiber contents under three fatigue load levels for 10 steel fiber reinforced concrete beams. With the increase of steel fiber content, the occurrence of cracks in steel fiber reinforced concrete beams will be delayed, and the fatigue life of steel fiber reinforced concrete beams will also increase. The greater the fatigue load level, the smaller the yield fatigue life and ultimate fatigue life of steel fiber reinforced concrete beams. This proves that the addition of steel fiber can improve the crack resistance of concrete,and then improve its fatigue life and enhance its fatigue performance. Elisa Poveda et al.[7] studied the effect of different fiber content on the compressive fatigue properties of steel fiber reinforced self-compacting concrete. The study found that the higher the fiber content,the longer the fatigue life, and the longer the fatigue life of the fiber content (0.6%).The test also verifies that the relationship between the strain rate and the fatigue life of each cycle is independent of the number of fibers, and only depends on the strength of the concrete itself. These studies have shown that the fatigue performance of concrete increases with the increase of steel fiber content, but after exceeding a certain limit content,it will reduce the improvement of fatigue performance of concrete, and even have a negative effect.Therefore, the appropriate content has a positive effect on the fatigue performance of concrete.

In addition to steel fiber,basalt fiber,glass fiber,synthetic fiber and so on are used in concrete. Basalt fiber has good physical and mechanical properties.Its excellent performance and concrete composite can improve the shortcomings of concrete itself,and improve the mechanical properties of concrete such as splitting tensile strength,flexural strength and flexural toughness.Bai Jianwen et al.[8] studied the fatigue performance of basalt fiber reinforced concrete with four kinds of fiber content (0.1%,0.2%,0.3%) at three different stress levels (0.75,0.7,0.65) by three-point bending fatigue test.The experimental data were analyzed by mathematical statistics and the fatigue equation was fitted. It is found that the bending fatigue life of basalt fiber reinforced concrete conforms to the two-parameter Weibull distribution, and with the decrease of stress level,the Weibull shape parameter decreases first and then increases, and the discreteness of bending fatigue life increases first and then decreases.With the increase of fiber content, the bending fatigue life distribution of concrete is more uniform,the dispersion is smaller, and the fatigue life is greatly increased by

32.7%-76.4%.This shows that the incorporation of basalt fiber can improve the fatigue performance of concrete and make the fatigue life of concrete more stable.Huang Ming et al.[9] carried out three-point bending loading fatigue tests on basalt fiber beams with different dosages (0.2%,0.3%,0.4%) under different stress levels. It was found that the bending fatigue life of basalt fiber concrete with different dosages obeyed the two-parameter Weibull distribution.Under the same stress level, the flexural fatigue life of basalt fiber reinforced concrete is much higher than that of plain concrete.The flexural fatigue life of basalt fiber reinforced concrete increases gradually with the increase of basalt fiber content,and the increase range is about 52.9% -99.6%.And through the principle of load work, the fatigue toughness was analyzed.It was found that the fatigue toughness of the basalt fiber to the concrete beam was improved, and with the increase of the content, the fatigue toughness of the concrete was greater, and the maximum increase was 80.6%.Kasaby EE et al.[10] used glass fiber with a length of 1.5mm to make square and rectangular foundations with a weight ratio of (0.20,0.30,0.35,0.40,0.50and1.00%).The tensile and fatigue properties of the foundation were studied experimentally,and the results of FGRC were compared with those of reinforced concrete.The results show that when the fiber content is 3.5 %, the reinforcement effect is consistent with that of the steel bar. When the fiber content is 1 %, the fatigue stress is increased by 28.6%.In contrast,Rendi Wu et al[11] used non-beam structural test blocks,using single hook and double hook steel fibers to prepare eight circular plates with a diameter of 800±2mm and a thickness of 75±2mm,and the bending fatigue test was carried out by central loading.It is found that the fatigue failure mode of ordinary concrete specimens is brittle failure, and SFRC is ductile failure.The peak drawing load of double hook steel fiber is 30 % higher than that of single hook steel fiber,which shows that the improvement of fatigue performance of double hook steel fiber is more obvious than that of single hook steel fiber.

Synthetic fiber reinforced concrete is a new type of concrete material that has developed rapidly in recent years.It can significantly improve the tensile toughness, frost resistance and wear resistance of concrete,and can effectively prevent early cracks in concrete.Polypropylene fiber is a kind of synthetic fiber,which has good strengthening and toughening effect,light weight,good corrosion resistance and high cost performance. Cen et al.[12] carried out three-point bending fatigue tests on pavement modified polypropylene fiber and polyacrylonitrile fiber concrete under different stress levels.It is found that these two kinds of fibers can improve the fatigue life of concrete by nearly double,which has a positive effect on prolonging the service life of pavement.The addition of synthetic fibers increases the toughness of concrete and slows down the development of cracks,thus improving the fatigue life of concrete.Kou Jialiang et al.[13] carried out the tension and compression fatigue test of high ductility polyvinyl alcohol fiber(PVA) concrete under constant amplitude repeated load,and studied its fatigue strength,times and life parameters under different stress levels.It is found that the fatigue curve of high ductility PVA fiber reinforced concrete has good regularity at high frequency.The fatigue failure of high ductility fiber reinforced concrete under tension and compression at different frequencies has an order of magnitude difference with the change of stress level.However, at the same stress level,the slope is not much different,which proves that the fatigue performance of high ductility PVA fiber reinforced concrete is relatively stable.Deng Zongcai et al.[14] studied the bending fatigue characteristics of modified acrylic fiber reinforced concrete beams by four-point bending test.The results show that when the volume fraction of acrylic fiber is 0.085 %,the bending fatigue strength of acrylic fiber reinforced concrete beams and acrylic fiber reinforced concrete beams with long steel fibers on the bottom layer is 11.7% and 15.7% higher than that of plain concrete, respectively.At the stress level of 0.9, the bending fatigue strength is more than 20 times that of plain concrete.With the increase of stress level, the fatigue strength ratio of fiber concrete and plain concrete increases, which shows that the effect of modified clear fiber on improving fiber concrete beam is remarkable.Xu Lihua et al.[15] studied the fatigue failure mode of polypropylene fiber concrete,clarified the deformation law,and established the fatigue strength and fatigue life equation through the two influencing factors of length-diameter ratio and volume fraction of polypropylene fiber. It is found that the fatigue failure of polypropylene fiber concrete has three forms,and the fatigue performance is the most obvious when the aspect ratio of polypropylene fiber is 280 and the volume fraction is 0.2%.Based on the two-parameter Weibull distribution model,the fatigue life equation with failure probability is established.In the above case,the stress level corresponding to the fatigue strength is increased by more than 30%.

Study on fatigue performance of hybrid fiber reinforced concrete

Hybrid fiber concrete refers to a type of concrete that uses two or more fibers and is mixed in concrete. Hybrid fiber concrete mainly makes up for the deficiency of using a single fiber by using the respective advantages of different fibers, resulting in a positive hybrid effect and achieving the effect of '1+1>2'.For example,steel fiber reinforced concrete has good toughness and fatigue resistance.When it is subjected to cyclic loading, the bridging effect of fibers can inhibit the development of cracks,and the pull-out of fibers will also consume part of the energy generated by cyclic loading.As a synthetic material fiber,polypropylene fiber has the advantages of low density, light weight,good dispersion and corrosion resistance.The incorporation of polypropylene fiber into concrete can effectively reduce the micro-cracks generated in the early stage of concrete hardening,reduce the porosity in the material, and improve the durability of concrete.The incorporation of steel fiber and polypropylene fiber into concrete at the same time, that is,the mixture of high elastic modulus material and low elastic modulus material,can make up for the deficiency of single fiber. If it is added in an appropriate proportion,it can produce 'super superposition effect ',which is superior to single fiber concrete and plain concrete.

Chen et al.[16] carried out four-point bending fatigue tests on plain concrete (C),polypropylene fiber reinforced concrete (PFRC),steel fiber reinforced concrete (SFRC) and steel-polypropylene hybrid fiber reinforced concrete (HFRC) under different stress levels.Based on the two-parameter Weibull distribution theory,the Weibull shape parameter a and the characteristic life parameter Na were obtained by graphical method,moment estimation method and maximum likelihood estimation method.The fatigue life of concrete under different failure probabilities was predicted and the double logarithmic fatigue equation was established.The results show that the bending fatigue test data of concrete under different stress levels conform to the two-parameter Weibull distribution.Fibers can improve the fatigue performance of concrete,and the improvement of hybrid fibers on the fatigue performance of concrete is better than that of single-doped fibers.In order to study the probability distribution and flexural fatigue properties of hybrid fiber reinforced concrete (HyFRC) containing different proportions of steel and polypropylene fibers, four-point bending fatigue tests were carried out by Vineet Bajaj et al.[17].The volume ratios of steel fiber and polypropylene fiber were 25%:75%,50%:50%and75%:25%,respectively, when the fiber volume fractions were 0.5%,1.0 % and 1.5 %,respectively. The probability distribution of HyFRC under different stress levels was established by using fatigue test data.The results show that in steel-polypropylene fiber concrete, with the increase of polypropylene fiber content,steel-polypropylene fiber concrete significantly reduces the variability of fatigue life distribution in terms of size and shape.Under the fatigue strength/endurance limit of 2million cycles,the combination of 50% steel fiber and 50% polypropylene fiber is most suitable for reducing variability and bending fatigue performance.Kai Cui et al.[18] studied the compressive fatigue properties of steel-polypropylene hybrid fiber reinforced concrete (HFRC) under fatigue compression at different stress levels.The effects of fiber parameters such as steel fiber volume fraction (1%,1.5% and 2%) and aspect ratio (30,60 and 80) and polypropylene fiber volume fraction (0.1%, 0.15% and 0.2%) and aspect ratio (167,280 and 396) on fatigue deformation,fatigue life and fatigue strength were analyzed.It is found that the ultimate fatigue deformation and fatigue strength of steel-polypropylene fiber concrete are 63% and 37% higher than those of plain concrete.Due to the positive synergistic effect of fiber mixing in the mixed system,HFRC is superior to polypropylene fiber reinforced concrete (PFRC) or steel fiber reinforced concrete (SFRC) in fatigue performance.Taotao Cui et al.[19] studied the bending fatigue behavior of steel-polypropylene fiber reinforced high strength lightweight aggregate concrete under different stress levels, including fatigue life and crack propagation process.The results show that compared with single fiber reinforced high-strength lightweight aggregate concrete, steel-polypropylene fiber has the smallest crack growth rate, the longest stable development stage and the longest fatigue life.

From the above research results,it can be found that compared with single fiber concrete,hybrid fiber concrete has more significant improvement in fatigue performance.In the case of suitable fiber mixing ratio,the fatigue strength and fatigue life of hybrid fiber are much higher than those of single fiber concrete.The constraint of light fiber on cracks makes up for the deficiency of high-strength fiber in this aspect, which makes the cracks of concrete structure develop slowly, and then improves the fatigue performance.Moreover,when the proportion of mixed fiber is appropriate,the discrete and variability of the fatigue life distribution of concrete is reduced,and the fatigue life of concrete is more stable and long-term.Therefore,the fatigue performance of mixed fiber concrete is more significant than that of single fiber concrete.

Conclusion

In summary,adding polypropylene fiber, steel fiber, glass fiber and carbon fiber to concrete,due to the three-dimensional random distribution of fiber in the concrete machine,the tensile strength of fiber is higher than that of concrete, so that the fiber can improve the fatigue strength of concrete, prolong the fatigue life, reduce the crack width,make the integrity of concrete better,and the elastic modulus is obviously improved.Among them, steel fiber has the greatest improvement in the mechanical properties of concrete,with an average increase of 30.5%-41.7%.Glass fiber and synthetic fiber have improved the mechanical properties of concrete,with an increase of 10.5%-14.6%;among them, the improvement of mixed fiber is significantly higher than that of single fiber,and the mechanical properties are improved by about 45%-59.2%.However, the current research results are all based on the fatigue test of fiber reinforced concrete, and the research on the fatigue performance of fiber reinforced concrete under multiple factors needs to be further studied.

In addition, the fatigue failure analysis of concrete structures is still a very challenging topic.Through the S-N curve method,Paris formula method,finite element method and damage constitutive model,the fatigue damage problem of fiber reinforced concrete can be comprehensively studied in many aspects.The damage constitutive model has a strict thermodynamic basis and can be based on physical laws.The evolution process of its internal variables is modeled and analyzed,so it has the most development potential.

At present,the research on fatigue performance is still limited to experiments,and there is no relevant mature and stable numerical simulation.Only by adhering to the discussion of the physical mechanism in the evolution process of concrete fatigue damage,it is possible to finally establish a perfect concrete structure fatigue analysis theory.

Disclaimer (Artificial intelligence)

Author(s) hereby declare that NO generative AI technologies such as Large Language Models (ChatGPT, COPILOT, etc.) and text-to-image generators have been used during the writing or editing of this manuscript.

References

[1] Wang Ruimin.Fatigue behavior of concrete structures[D].Dalian:Dalian University of Technology, 1989.

[2] Zhu Jinsong,Zhu Xiancun.Simplified analysis method for fatigue cumulative damage failure process of reinforced concrete bridges[J].Engineering Mechanics,2012,29(5):107-114+121.

[3] Zhang Zhibiao,Guo Mengmeng,Zhu Rulin,Feng Zhongren.Experimental study on the effect of steel fiber content on the tensile fatigue performance of concrete[J],Zhongwai Highway,2021,41(2): 291-295.

[4] Gao Danying,Zhang Ming,Zhao Jun.Calculation method for crack width of steel fiber reinforced high-strength concrete beams under fatigue load[J].Journal of Civil Engineering,2013,46(3):40-48.

[5] Mei Yingjun,Zhao Xiang,Dai Chao, Xiang Chao.Fatigue Life of Steel Fiber Reinforced Polymer Concrete under Bending Load[J].Highway Traffic Technology,2015,32(9):20-25.

[6] Feng Zhongren,Lyu Eryan,Guo Mengmeng.Fatigue test of steel fiber reinforced concrete beams under cyclic loading[J].China-foreign highway,2020,40(5):191-195.

[7] Elisa Poveda, Gonzalo Ruiz a, Héctor Cifuentes,Rena C. Yu, Xiaoxin Zhang.Influence of the fiber

content on the compressive low-cycle fatigue behavior of self-compacting SFRC[J].International Journal of Fatigue,2017,101:9-17.

[8] Bai Jianwen,Zhao Yanru,Su Song.Study on flexural fatigue properties of basalt fiber reinforced concrete[J].Industrial building,2022,52(07):186-191+127.

[9] Huangmin,Chen Gang,Zhao Yuru.Study on fatigue life and toughness of basalt fiber reinforced concrete under bending load[J].Journal of Henan Polytechnic University(Natural Science Edition),2022,41(1):159-173.

[10] Kasaby EE, Bdelmagied MFA. Performance of Isolated Footings Reinforced Randomly by Glass Fiber. J. Eng. Res. Rep. [Internet]. 2019 Jun. 24 [cited 2025 Jan. 3];6(1):1-8.

[11] Rendi Wu,Qian Gu,Shui Tian,Xu Gao,Yue Liu,Bin Sun,Xiang Wang.Flexural fatigue behavior of hooked-end steel fibres reinforced concrete using centrally loaded round panel test[J].Materials and Structures,2023,56:137.

[12] Cen Guoping,Wang Jinhua,Wang Shuotai.Bending fatigue test of pavement synthetic fiber reinforced concrete[J].Concrete,2009(03):41-43.

[13] Kou Jialiang,Zhao Kunlong,Zhang Haobo.Experimental study on tension and compression fatigue performance of high ductility fiber reinforced concrete[J].Journal of Civil Engineering,2018,51(9): 17-25.

[14] Deng Zongcai,Wang Zhangshui,Zhang Guoqing,et al.Bending fatigue properties of modified acrylic fiber reinforced concrete beams[J].Journal of Tsinghua University(Natural Science Edition),2003(11): 1550-1553.

[15] Xu Lihua,Li Xuefeng,Chi Yin,et al.Fatigue life analysis of polypropylene fiber reinforced concrete under uniaxial compression[J].Journal of Hunan University(Natural Science Edition),2023,50(3): 121-131.

[16] Chen Meng,Guo Sha,Lu Zhe 'an,et al.Experimental study on fatigue performance of hybrid fiber reinforced concrete[J].Concrete,2010(9):46-48.

[17] Vineet Bajaj，Surinder Pal Singh，Amrit Pal Singh，Surendra Kumar Kaushik.Flexural fatigue analysis of hybrid fibre-reinforced concrete[J].Magazine of Concrete Research,2012,64(4):361-173.

[18] Kai Cui,Lihua Xu,Lijian Li,Yin Chi.Mechanical performance of steel-polypropylene hybrid fiber reinforced concrete subject to uniaxial constant-amplitude cyclic compression: Fatigue behavior and unified fatigue equation[J].Composite Structures,2023,311:116795.

[19] Taotao Cui,Baokuan Ning,Xinxin Shi,Jinyu Li.Flexural fatigue behavior of hybrid steel-polypropylene fiber reinforced high-strength lightweight aggregate concrete[J].Construction and Building Materials,2023,337:131079.