Journal of Engineering Research and Reports

Volume 26, Issue 11, Page 156-162, 2024; Article no.JERR.126104
ISSN: 2582-2926

Study on Mechanical Properties of Fiber-reinforced Cement-based Materials

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Author's contribution

The sole author designed, analysed, interpreted and prepared the manuscript.

Article Information

DOI: https://doi.org/10.9734/jerr/2024/v26i111321

Open Peer Review History:
This journal follows the Advanced Open Peer Review policy. Identity of the Reviewers, Editor(s) and additional Reviewers, peer review comments, different versions of the manuscript, comments of the editors, etc are available here: https://www.sdiarticle5.com/review-history/126104

Review Article

Received: 26/08/2024
Accepted: 30/10/2024
Published: 04/11/2024

ABSTRACT

Fiber reinforced cement-based materials are used to add various kinds of fibers to ordinary cement-based materials to improve their tensile strength, compressive strength, shear strength, flexural strength, flexural strength and impact resistance. There are many kinds of fiber, including steel fiber, carbon fiber, glass fiber, polypropylene fiber and basalt fiber, etc. The type, shape, content and length-diameter ratio of fiber will affect the performance of cement-based materials. In this paper, the research status of steel fiber, polypropylene fiber and basalt fiber on cement-based materials is reviewed, and the application of fiber reinforced cement-based materials is prospected.

Keywords: Steel fiber; polypropylene fiber; basalt fiber; fiber reinforced.

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Cite as: *Jin, Congying. 2024. "Study on Mechanical Properties of Fiber-Reinforced Cement-Based Materials". Journal of Engineering Research and Reports 26 (11):156-62. https://doi.org/10.9734/jerr/2024/v26i111321.*

1. INTRODUCTION

Cement-based composites are widely used because of their low price and strong practicability. Although it is widely used, its disadvantages also hinder the development of building structures. For example, Cement-based composite materials have relatively weak tensile properties and crack resistance, leading to reduced overall structural performance. With the continuous progress of our society and the continuous development of various industries, the construction industry has also developed in high speed. China's building construction is also more and more, so the performance of existing building materials put forward high requirements. Fiber-reinforced cement-based materials add some fibers to the cement-based substrate, improving the characteristics of low strength and poor toughness of the ordinary cement base. At the same time, it also has the functions of anti-freezing and anti-corrosion that cement base does not have. In addition, cement base is also an important direction of contemporary research on high-performance cement-based composite materials (Chen 2019, Wu 1999).

Cement-based composite materials have disadvantages such as low tensile strength, poor toughness and difficult to control crack width after cracking. Therefore, the traditional reinforced cement-based composite materials have cracks due to the influence of external environment, and the existence of cracks makes the internal steel bars of cement-based composite materials rust and engineering accidents occur (Yang et al., 2008, Zhang et al., 2021). A large number of studies have shown that the speed of deterioration of the structural properties of cement-based composites mainly depends on the rate of intrusion of harmful ions such as water, carbon dioxide and chloride ions into the interior of cement-based composites, and the appearance of cracks in cement-based composites will greatly accelerate the intrusion of these harmful media into the interior of cement-based composites. Eventually, it will lead to premature deterioration of the cement-based composite structure or even complete loss of function, that is, the cracks of the cement-based composite structure directly affect the durability of the structure and the service life of the project. In order to overcome these shortcomings of cement-based composites, polypropylene fiber cement-based composites and steel fiber cement-based composites with fiber content less than 2% have been developed. Fiber-reinforced cement-based composite is a kind of composite material which is formed by the hardening cement slurry formed after the hydration and hardening of cement and the discontinuous short fiber or continuous long fiber as the reinforcement material (Zhang et al., 2010).

Cement-based composites increase the cost due to the addition of fibers, but the performance of the material is determined by the volume of fiber content, if the fiber content is not high, the density has little impact on its working performance and mechanical properties, but it can affect the cost. Therefore, under the condition of the same volume content, the weight of the dense fiber is larger than that of the low-density fiber, and the cost is also higher. For cement-based composite materials, the addition of fiber can undoubtedly improve its crack resistance, bending toughness and impact resistance, and also improve the impermeability, frost resistance, fatigue resistance and wear resistance of cement-based materials, so as to improve the durability of cement-based composite materials.

Studies on the mechanical properties, toughness and deformation properties of cement-based composites enhanced by different fibers (such as steel fiber, polypropylene fiber and alkali-resistant glass fiber, etc.) show that the addition of fibers can effectively improve the mechanical and deformation properties of cement-based composites, and the improvement effect tends to be obvious with the increase of fiber content within a certain range (Wang and Wu 2003, Deng and Ding 2020). Fiber cement based composites not only have excellent properties, but also have greater economic value. Therefore, fiber cement based composites have wide application prospects.

2. FIBER REINFORCED CEMENT BASED MATERIAL

2.1 Steel Fiber

Steel fiber is the first fiber used to strengthen the cement matrix, and in 1910, American researchers proposed the theoretical idea of steel fiber reinforced cement. In the early 1970s, the United States developed a process for drawing molten steel to produce cheap steel fibers to increase the use of steel fiber cement-based building materials. At present, steel fibers can be added to the cement matrix by spraying steel fibers or laying steel fibers on top and bottom. Sprayed steel fibers are steel fibers that are added to a cement matrix and then sprayed onto the surface of a building structure by compressed air. When cement or concrete is poured, the upper and lower laminate steel fibers are artificially and evenly spread over the top and bottom 20mm planes. In addition, steel fibers can be prepared by centrifugal molding in a circumferential or axial two-dimensional distribution, thereby improving the tensile strength and cracking resistance of the annular part of the building material. Steel fiber cement based composite material has excellent tensile, crack resistance, toughening, fatigue resistance and impact resistance and other mechanical properties, with "crack but not broken" as the damage characteristics, suitable for bridge deck pavement layer, airport runway, railway sleeper, shield segment, civil building floor and prefabricated component overlap location of complex stress distribution, fatigue and impact resistance parts or parts.

Since its advent, steel fiber cement based composites have been widely studied for their superior mechanical properties and deformation properties (Qiu et al., 2020, Liu et al., 2020). Compared with ordinary cement-based composites, the introduction of steel fiber significantly improves the ductility and crack resistance of the matrix, making it possess higher tensile and shear properties, and overcomes the shortcomings of cement-based composites such as weak tensile strength and poor ductility deformation (Su et al., 2020).

Common types of steel fiber mainly include round straight type, end hook type, dumbbell type and wave type. The bond strength of steel fiber with different morphology and concrete matrix is different, which will lead to the great difference in the mechanical properties of steel fiber concrete after hardening. Li (1992) compared the influence of steel fibers produced by different processing processes on the mechanical properties of concrete, and found that the steel fibers produced by the steel strip cutting method and the steel block milling method had the best reinforcement effect, which may be due to the fact that the steel fibers produced by these two methods have the characteristics of distortion and hook, so as to improve the bonding properties by improving the mechanical anchoring force with the matrix. Although the research shows that the higher the steel fiber content, the better the enhancement effect, but the content of shaped steel fiber should generally be less than 2.0%, and when the content is too high, it is easy to cause uneven dispersion due to "agglomeration". In order to improve the dispersibility of steel fibers on the basis of increasing the bonding strength, water-soluble glue is used to bond single steel fibers into rows in the production process of the front end hooked steel fibers to make the tandem end hooked steel fibers. This method can achieve "two dispersions" of steel fibers in the stirring process, and ensure that steel fibers do not "cluster" and disperse evenly (Xie and Han 1994). Other surface modification methods for steel fibers, such as the use of nano-silica (Pi et al.,2019) or silane coupling agent (Liu et al., 2020), have not been reported to have an effect on the dispersion of steel fibers, although studies have shown that they can improve the interface bonding properties.

The addition of steel fiber into cement-based composite materials not only improves the strength and toughness of high-strength concrete, but also hinders the development of macro-cracks, delays the development of micro-cracks into macro-cracks, and improves the ductility after the formation of macro-cracks (Holschemacher et al., 2010). Silva (2010) used a high-speed hydraulic servo testing machine to carry out tensile experiments of fiber concrete under different strain rates, and found that when the strain rate increased, the dynamic shear stress between fiber and concrete matrix also increased. Therefore, the reason for the increase in the spalling strength of fiber reinforced concrete under dynamic loading is not only the crack growth factor of plain concrete, but also the increase in the dynamic shear stress between fiber and matrix. At the same time, after crack growth occurs in the matrix, the steel fibers in the concrete matrix will be blocked by the fibers when cracks pass through these fibers, and the direction of the extender will be delayed. At the same time, due to the bridging effect of steel fibers, multistage branch cracks appear around the main cracks in the matrix, which effectively prevents the further evolution of tensile damage.

Wu et al. (2005), Wang (2004) studied the mechanical properties of mixed reinforced cement mortars with steel fibers of different sizes (micro-fine and medium). The results show that hybrid steel fiber can improve the mechanical properties of cement mortar better than single diameter steel fiber when the volume fraction of steel fiber is constant. (Ahmed 2009) conducted tensile tests on steel fiber reinforced cement-based composites in 2009. The test results show that the ultimate tensile strength of the steel fiber cement-based composite with a water-binder ratio of 0.27 and a steel fiber volume content of 2.0% is up to 4.8MPa, and its corresponding tensile strain is 1%. The crack width is not measured in this study. Wu et al. (2018) studied the interfacial bonding properties and flexural properties of embedded steel fibers with different shapes (straight fiber, hook fiber and corrugated fiber) and UHPFRC matrix with 15% or 20% silica ash content under different curing times. The research results showed that the bonding properties of corrugated fiber and hook fiber were significantly improved by 3-7 times compared with straight fiber. The flexural strength of UHPFRC of corrugated fiber and hook fiber is increased by 8%~28% and 17%~50% respectively. Rezakhani et al., (2021) studied the influence of four steel fiber types (straight ZP305, wavy Nycon and smaller BekaertOL10mm / 6mm steel fiber) on the mechanical properties of ultra-high performance fiber reinforced concrete. The results show that the shape and size of steel fiber have little influence on the quasi-static properties of UHPFRC during compression, but have great influence on the bending and tensile properties. Esmaeili et al., (2021) studied the tensile properties of ultra-high performance fiber reinforced concrete when the Angle of the end of hooked steel fiber increased from 0° to 90°. The research results showed that the mechanical properties of the fiber varied according to the diameter and Angle of the fiber. When the Angle of hooked fiber is increased from 0° to 90°, the pull-out force of hooked fiber and semi-hooked fiber is increased by about 35% and 15%, respectively. Shin et al., (2021) studied the effect of steel fiber type on the mechanical behavior of UH-PFRC, and the results showed that curved steel fiber exhibited better tensile properties than straight steel fiber, and its effectiveness increased with the increase in the number of reinforcing bars.

2.2 Polypropylene Fiber

Polypropylene fiber has excellent mechanical properties, chemical erosion resistance and corrosion resistance, and can be widely used in fiber concrete industry. Polypropylene fiber has been effectively applied in textile chemical industry and structural engineering. Today, polypropylene fibers have been widely used in the concrete industry.

Yin et al., (2024) conducted compressive and flexural tests on polypropylene fiber (PP) reinforced cement-based composites and found that the addition of PP fiber could improve the compressive toughness of fiber reinforced cement-based composites (FRCC), improve the failure mode of the composite, and cause the ductile failure of FRCC with multiple micro-cracks. When the fiber content is 2%, the compressive strength of FRCC is the highest. When the PP fiber content is greater than 2%, due to the excessive fiber content, the matrix compactness of the composite material is reduced or the fiber dispersion is uneven, thus reducing the compressive strength of the specimen. The addition of PP fiber can provide the function of bridge crack for FRCC, improve the bearing capacity and crack resistance of the composite, and avoid the brittle failure of the composite. Liang et al., (2017) analyzed the effects of different sizes of polypropylene fibers and their hybrid fibers on the flexural toughness of concrete, and found that the smaller the diameter and the shorter the length of polypropylene fibers, the more obvious the enhancement effect on the flexural toughness of concrete. Wang et al., (2021) studied the effects of basalt fiber and polypropylene fiber on the mechanical properties of concrete, and found that with the increase of fiber volume fraction, the mechanical properties of concrete were improved to varying degrees, and the bending strength and splitting tensile strength were significantly improved. Yuan et al. (2021) studied the effects of glass fiber and polypropylene fiber content and water-binder ratio on the mechanical and microstructural properties of concrete, and found that the fiber content and water-binder ratio had a coupling effect on the mechanical properties of concrete. In conclusion, the study of the effect of polypropylene fiber on the mechanical properties of ordinary concrete is mature.In order to improve the strength and brittleness of ceramsite concrete, Gu et al. (2024)[28] added polypropylene fiber to ceramsite concrete, prepared 180 polypropylene fiber reinforced ceramsite concrete specimens, and carried out cube compression test, splitting tensile test, axial compression test and elastic modulus test. The results show that polypropylene fiber can effectively improve the splitting tensile strength and tensile compression ratio of ceramite concrete, and the influence of compressive strength and elastic modulus is relatively small.

2.3 Basalt Fiber

Basalt fiber is a continuous fiber made of natural basalt ore by high temperature melting. This kind of fiber has a wide range of materials, superior mechanical properties, belongs to high-performance inorganic fiber, and has distinct environmental protection characteristics, with its good acid and alkali resistance, corrosion resistance, chemical stability and high cost performance, mechanical properties and in construction, road and bridge engineering practice has been widely used. Basalt fiber has good compatibility with cement, and has good binding force. After adding concrete, a variety of composite materials with wide application range and excellent performance can be prepared, which is one of the research hotspots in the construction industry.

Liu et al. (2024) studied the effect of basalt fiber on the mechanical properties of scoria light aggregate concrete and analyzed its toughening mechanism. The test results show that the toughness of scoria light aggregate concrete increases significantly with the increase of basalt fiber content. Especially when the basalt fiber content reaches 3‰, the compressive strength of concrete is increased by 2%, and the bending strength is significantly increased by 33.4%, reaching the optimal content point. In addition, by scanning electron microscopy (SEM) observation, it is found that the bonding property of basalt fiber and cement stone interface is enhanced, and the porosity is reduced, which improves the compactness and stability of concrete. In order to clarify the differences in shear bearing capacity and shear failure process of concrete beams with different basalt fiber content, Li (2024) observed the shear failure process of reinforced concrete beams with unmixed fiber, 1kg/m3 basalt fiber and 2kg/m3 basalt fiber through laboratory model tests, recorded the failure loads and made comparisons. The results show that basalt fiber can improve the cracking and shear properties of concrete beams, and the improvement amplitude is more obvious with the increase of fiber dosage. When 1kg/m3 fiber is added, the shear performance of the concrete specimen is improved but the range is small. When the basalt fiber content is further increased to 2kg/m3, the shear performance of the concrete specimen is very obvious. Moreover, after the shear failure, the reinforced concrete beam specimen still maintains high toughness, and can still operate normally for a period of time after the failure, with strong impact failure resistance.

3. CONCLUSION

With the concept of sustainable development gradually gaining popularity, the future development direction of architecture must be green and environment-friendly architecture. Therefore, the future fiber-reinforced cement-based composites may have the following development trends. Natural plant fiber reinforced cement-based composite. These materials are inexpensive, renewable and degradable, in line with the concept of green building. Traditional chemical fiber materials consume a lot of energy and are susceptible to environmental pollution during use. In addition, the research of natural plant fiber reinforced cement-based composites is still in its infancy, and the strengthening effect of natural plant fiber has not yet been developed. Therefore, the vigorous development of natural plant fiber reinforced cement-based composites will become the mainstream research direction. Fiber reinforced cement-based composites can effectively strengthen concrete structures and provide better engineering performance. With the continuous improvement of the national economic level, there will be more and more super high-rise buildings, large buildings, and more buildings will be built in harsh areas such as oceans and deserts, and the performance of concrete materials will be a higher requirement. Therefore, fiber-reinforced cement-based composites will have broad development prospects in the future.

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.

COMPETING INTERESTS

Author has declared that no competing interests exist.

REFERENCES

Ahmed, S. F. U., & Maalej, M. (2009). Construction and Building Materials, 23(1), 96-106.

Chen, W. Y. (2019). Research status and development trend of fiber reinforced cement-based materials. *Building Materials*, 46(10), 147-148.

Deng, Z. C., & Ding, J. M. (2020). Experimental study on the dispersibility and flexural toughness of basalt fibers in BFRC. *China*

Concrete and Cement Products, (1), 47-50.

Esmaeili, J., Andalibi, K., Gencel, O., et al. (2021). Pull-out and bond-slip performance of steel fibers with various ends shapes embedded in polymer-modified concrete. *Construction and Building Materials*, 271, 121531.

Gu, F., Li, Z. Q., Yang, Y., et al. (2024). Experimental study on basic mechanical properties of polypropylene fiber-reinforced ceramsite concrete. *Bulletin of the Chinese Ceramic Society*, 43(10), 3572-3584.

K., Mueller, T., & Ribakov, Y. (2010). *Materials & Design*, 31(5), 2604-2615.

Li, D. (2024). Analysis of the enhancing effect of basalt fiber on the shear capacity of concrete beams. *Transpo World*, (21), 150-154.

Li, J. Z. (1992). Processing technology and characteristics of reinforced concrete steel fiber. *New Tech New Proc (in Chinese)*, (5), 2–8.

Liang, N. H., Zhong, Y., & Liu, X. R. (2017). Experimental study of flexural toughness for multi-scale polypropylene fiber reinforced concrete. *Journal of Central South University (Science and Technology)*, 48(10), 2783-2789.

Liu, Q. S., & Fu, D. T. (2024). Effect of basalt fiber on the strength of volcanic slag lightweight aggregate concrete. *Northern Architecture*, 9(5), 18-21.

Liu, T. J., Wei, H. N., Zhou, A., et al. (2020). Multiscale investigation on tensile properties of ultra-high performance concrete with silane coupling agent modified steel fibers. *Cem Concr Compos*, 111, 103638.

Liu, Y. W., Shi, C. J., Zhang, Z. H., et al. (2020). Mechanical and fracture properties of ultra-high performance geopolymer concrete: Effects of steel fiber and silica fume. *Cem Concr Compos*, 112, 103665.

Pi, Z., Xiao, H., Du, J., et al. (2019). Interfacial microstructure and bond strength of nano-SiO2-coated steel fibers in cement matrix. *Cem Concr Compos*, 103, 110.

Qiu, M. H., Zhang, Y., Qu, S. Q., et al. (2020). Effect of reinforcement ratio, fiber orientation, and fiber chemical treatment on the direct tension behavior of rebar-reinforced UHPC. *Constr Build Mater*, 256, 15–23.

Rezakhani, R., Scott, D. A., Bousikhane, F., et al. (2021). Influence of steel fiber size, shape, and strength on the quasi-static properties of ultra-high performance concrete: Experimental investigation and numerical modeling. *Construction and Building Materials*, 296, 123532.

Shin, H. O., Wkim, K., Oh, T., et al. (2021). Effects of fiber type and specimen thickness on flexural behavior of ultra-high-performance fiber-reinforced concrete subjected to uniaxial and biaxial stress. *Case Studies in Construction Materials*, 15, e00726.

Silva, F. A., Butler, M., Mechtcherine, V., et al. (2011). *Mater Sci Eng: A*, 528(3), 1727-1734.

Su, J., Shi, C. J., Qin, H. J., et al. (2020). Dimensional effect of bending strength of ultra-high performance concrete. *J Chin Ceram Soc*, 48(44), 1740–1746.

Wang, C. Q. (2004). Study of different geometric size hybrid steel fiber reinforced cementitious composites (Master's thesis). School of Material Science and Engineering of Tongji University, Shanghai.

Wang, C. Q., & Wu, K. R. (2003). Study on the mechanical properties of carbon fiber and steel fiber concrete. *Journal of Building Materials*, 6(3), 253-256.

Wang, D. H., Ju, Y. Z., Shen, H., et al. (2019). Mechanical properties of high-performance concrete reinforced with basalt fiber and polypropylene fiber. *Construction and Building Materials*, 197(2), 464-473.

Wu, K. R., & Li, S. J. (2005). Study of mechanical properties of different size hybrid steel fiber reinforced cement mortar. *Journal of Building Materials*, 8(6), 599-604.

Wu, Z. W. (1999). The future of fiber-reinforced cement-based composites. *Chin Concr Cem Prod*, (1), 5–62.

Wu, Z., Wkhayat, K. H., & Shi, C. (2018). How do fiber shape and matrix composition affect fiber pullout behavior and flexural properties of UHPC? *Cement and Concrete Composites*, 90, 193-201.

Xie, B. H., & Han, S. S. (1994). The status quo and prospects of the development of steel fiber production in China. In *The 5th National Conference on Fiber Cement and Fiber Concrete* (pp. 567–573). Guangdong, China.

Yang, C. J., Huang, C. K., Che, Y., et al. (2008). Mechanical properties and impermeability of hybrid fiber reinforced concrete. *Journal of Building Materials*, 11(1), 89-93.

Yi, Y. G., Zhang, Q., Yang, Y. P., et al. (2024). Study on basic mechanical properties of polypropylene fiber reinforced cement-based composites. *Jiangxi Building Materials*, (3), 14-16.

Yuan, Z., & Jia, Y. M. (2021). Mechanical properties and microstructure of glass fiber and polypropylene fiber reinforced concrete: An experimental study. *Construction and Building Materials*, 266(1), 1-13.

Zhang, Q., Gong, S. S., Zhao, Y. S., et al. (2021). Mechanical properties of multi-scale fiber compound reinforced cement-based materials. *Journal of Civil and Environmental Engineering*, 43(2), 123-129.

Zhang, X. F., Xu, S. L., & Li, H. D. (2010). Theoretical analysis of flexural performance of plain concrete composite beams strengthened with ultra-high toughness cementitious composite. *China Civil Engineering Journal*, 43(7), 51-62.

Peer-review history:
The peer review history for this paper can be accessed here:
https://www.sdiarticle5.com/review-history/126104