Review Article

Research Progress on Properties of Fiber Cement-based Composites

ABSTRACT

The addition of fiber improves the low strength and toughness of cement-based composites, and also improves the mechanical properties and rheological properties of cement-based composites. The types of fibers include polypropylene fiber, steel fiber, polyvinyl alcohol fiber, polyacrylonitrile fiber, etc., and the type, shape, content and aspect ratio of fibers will affect the properties of cement- based composites. The research status, existing problems and future research directions of fiber reinforced cement-based composites were reviewed, especially the effect of steel fiber on the rheological properties of cement-based composites. The application prospect of fiber cement matrix composites is also prospected.

Keywords: fiber; cement-based composites; rheological property

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, the tensile properties and crack resistance of cement-based composite materials are relatively weak, which leads to the overall structural performance of the project is low. 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[1-2].

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[3-4].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[5].

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.

Polypropylene fiber has the most obvious improvement on the high temperature and burst resistance of cement-based composites. Polyacrylonitrile fiber has the strongest inhibition effect on the shrinkage of cement-based composites. Steel fiber can improve its impact resistance and tensile properties; Polyvinyl alcohol fiber can improve its early cracking resistance. For example, the density of PVA fiber is much smaller than that of traditional steel fiber, so the cost of steel fiber is higher in order to achieve the same mechanical properties[6].Fiber cement based composite material has the characteristics of ultra-high toughness, multi-crack cracking and strain hardening, which not only makes the material itself have good physical properties, but also reduces the invasion of corrosive substances to a large extent, and plays a good role in protecting the internal structure. The application of composite fiber can obtain the performance of cement-based composite materials in terms of comprehensive properties compared with the application of single fiber. The use of steel fiber and polypropylene fiber composite fiber to improve the mechanical properties of cement-based composite materials, but also to improve the fire resistance and burst resistance of cement-based composite materials. The composite fiber of polypropylene fiber and PVA fiber can improve the mechanical properties and early crack resistance of cement-based composite materials[7]. This also makes cement-based composites more able to meet the current needs.

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[8-9]. 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. STEEL FIBER CEMENT BASED COMPOSITE MATERIAL

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[10-11]. 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[12].

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[13] 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[14]. Other surface modification methods for steel fibers, such as the use of nano-silica[15] or silane coupling agent[16], 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[17]. Silva[18] 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.[19-20]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[21] 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.

2.1Rheological properties of steel fiber reinforced concrete

The addition of steel fiber has a great influence on the rheological properties of concrete, and its content, length-diameter ratio and type will affect the rheological properties of concrete. The rheological parameters mainly include yield stress and plastic viscosity.

The yield stress refers to the minimum shear stress at which the fluid starts to flow, which is used to characterize the difficulty of the flow of the concrete mix. It is generated by the formation of flocculation network structure of solid particles and the adhesion and friction between particles[22]. Plastic viscosity is used to characterize the rate of deformation of freshly mixed concrete under shear stress, which mainly comes from the force between particles[23]. The forces between particles can be divided into gravitational forces (van der Waals forces) and repulsive forces (steric and electrostatic repulsive forces). Gravity can cause the mixture to form a flocculated network structure, resulting in increased viscosity. The repulsive force will disperse the flocculated structure, resulting in a decrease in viscosity, so the change of plastic viscosity depends on the size of the gravitational and repulsive forces between the particles[24].

Djamila et al.[25] studied the influence of steel fiber content on the rheological properties of steel-fiber concrete by using end-hook steel fiber with a lengthed-diameter ratio of 55. The fiber content was 0, 0.2% and 0.5% respectively. The results show that the yield stress increases with the increase of fiber content. The plastic viscosity decreased slightly. Marco et al.[26] used end-hook steel fibers with a length-to-diameter ratio of 64, and the fiber content was 0, 0.5%, 0.75% and 1.0%. The results show that both yield stress and plastic viscosity increase with the increase of fiber content. Katherine G et al.[27] adopted short steel fibers with a length-to-diameter ratio of 37.5, with fiber content of 0, 1.0%, 2.0% and 4.0%. The results show that with the increase of fiber content, the yield stress decreases first and then increases, and the plastic viscosity decreases. Tomasz et al.[28] studied the effect of steel fibers with different lengths and contents on the rheological properties of steel fiber concrete. The fiber lengths are 6mm and 13mm, and the fiber contents are 0.1%, 0.3% and 0.5%. The results show that the yield stress and plastic viscosity increase with the increase of fiber length. With the increase of fiber content, the yield stress increases, but the plastic viscosity changes little. From the above test results, it can be seen that the influence of length-diameter ratio and dosage of steel fiber on yield stress is relatively regular, but the influence on plastic viscosity is relatively small. When the volume content of steel fiber is constant, the larger the length-diameter ratio, the greater the probability of the steel fiber overlapping into a network, the less easily the steel fiber dispersing, resulting in the worse the fluidity of its mix. When the length-diameter ratio is unchanged, the greater the steel fiber content, the more likely it is to collide and mechanical interlock between steel fibers, and the collision between steel fibers will lead to additional energy consumption, which will reduce the fluidity of the mix. And when the fiber length is too long or the fiber content is too much, once the fiber reaches a certain critical volume fraction, the mechanical interlocking or winding of the fiber may dominate the flow behavior, and the mixture is not easy to flow, and the steel fiber in the matrix may not be easy to rotate and there is the possibility of "clumping". Zhang Qianqian et al.[29] found that when the steel fiber content increased to 1% and 3%, the yield stress increased by 48.5% and 133%, and the plastic viscosity increased by 39.4% and 82.3%, respectively. Sandy et al.[30] studied the effects of different length-diameter ratios of steel fiber and fiber content on the rheological properties of concrete, and the fiber content was 3%, 4%, 5%, 6%, 7% and 10%, respectively. The results show that when the fiber content is 5%, the plastic viscosity is half lower than that without fiber, and the yield stress is basically unchanged. When the fiber content exceeds 6%, both the yield stress and the plastic viscosity increase disproportionately. For long fibers, at a fiber content of 4%, although there is only a slight increase in yield stress and viscosity compared to concrete without fiber, it contains a high concentration of fiber clumps, so this concrete is no longer suitable for practical applications.

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.

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