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Analysis of Hybrid Effect of Two Hybrid Fiber CGFRP Bar and Its Mechanical Properties

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Abstract. Using two or more different fiber mixed form high-powered composite reinforcement, through the control of the amount of fiber bundles, to "hybrid excellent", can not only ensure the tensile strength, and can effectively improve the toughness of the FRP bar . The paper based on the theory of the composite material hybrid effect of carbon fiber and glass fiber hybrid form the CGFRP bar hybrid mode, mixed ratio, hybrid effect analysis and research, this paper expounds the influence of the main factors CGFRP bar ductility, puts forward the CGFRP bar effect positive hybrid fiber critical size, stress-strain curve, tensile strength and elastic modulus calculation method, ensure the use of performance under the premise, and put forward the CGFRP bar design idea of reinforced concrete structure FRP ductility design, improve the safety of the structure provides an effective way.

Introduction

In recent years, steel bar corrosion in civil engineering works structure and infrastructure is constantly intensifying, having brought on enormous economic losses to every country. According to statistics, in all structural damages, steel bar corrosion damage makes up 55%. Especially corrosion and damage to steel bar concrete infrastructure represented by bridge has become conspicuous problem in the world of today. In this condition, research and application of fiber reinforced polymer (FRP) bar, a corrosion-resistant fiber polymeric material used at home and abroad as substitute for steel bar, will become an effective method to solve steel bar corrosion problem.

Compared with steel bar, although FRP bar is higher in tensile strength, having superior elasticity property, but in the course of suffering force, simple fiber is different from steel bar in mechanical characteristics for yield, showing elasticity relation without yield point, stress-strain relation being always in linear change. While destruction, it will break down suddenly. So when replacing steel bar by simple fiber FRP bar in concrete structure, brittle fracture without obvious presage will happen, frightful hidden danger in safety existing, unlike steel bar concrete components, which shows good ductility property. This fact restricts generalization of FRP bar in civil engineering. Adopting over two kinds of different fibers to mingle to form high performance composite bar, reaching “crossbreeding excellence” by controlling amount of various kinds of fibrous bundle can not only guarantee tensile strength needed, but also effectively heighten toughness of FRP bar. According to hybrid effect theory of composite material, this treatise has conducted analytical research to positive hybrid effect of FRP bar, conducting analytical calculation on critical volume, stress – strain curve, tensile strength and elastic modulus of positive hybrid effect of CGFRP bar, putting forward train of thoughts of design for CGFRP bar in the premise of guaranteeing performance in service. By adopting hybrid FRP bar, we not only replace part of costly fiber by cheaper fiber to reduce cost. The key lies in heightening deformability of FRP bar. Research of this treatise has supplied an efficient path to conduct ductility design for concrete structure of FRP bar and to guarantee structural safety.

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Analysis of hybrid effect of FRP bar

Mingling of two kinds of fibers possesses excellent properties not possessed by simple fiber, mainly exhibiting in being able to heighten strength, rigidity and impact toughness, etc. of material, making its comprehensive mechanical properties improve greatly. For example, mingling small quantity of carbon fiber can make strength, rigidity and fatigue resistance improve of GFRP. By regulating volume percent of hybrid fiber, we can obtain composite material with different performance to adapt needs of various kinds of structure, making degree of freedom of design and selecting material increase greatly.

There are many kinds of composite material, with many changeable parameters. But not any matrix, any fiber and any volume ratio can obtain good hybrid effect. When positive hybrid effect appears in hybrid composite material, certain basic performances can be changed, but some negative hybrid effect can also appear along with it, making some performances lower down. Therefore, when conducting design of hybrid FRP bar, only by sufficiently mastering hybrid regularity of fiber to obtain positive hybrid effect, can we reach anticipated target.

Hybrid method. Fiber hybrid structure mainly consists of many modes including even hybrid, inner layer hybrid, interlayer hybrid, sandwich structure and combination hybrid structure, etc. Because that for fiber hybrid structure, there are more than two kinds of reinforcement phase (continuous fiber), performances of fiber, proportioning and hybrid form, performances of matrix, interfacial performances and various kinds of random defect influence performances of FRP in different degrees. Its principle of work is much more complicated than simple FRP. So far, no mechanical model with universal significance and relevant hybrid effect theory has been obtained. At present main research method aims at certain specific system to conduct conceptual design, experimental research and theoretical treatment. Sandwich structure is usually adopted for commonly used CGFRP hybrid method for reinforcing concrete structure, for example, mingling carbon fiber and glass fiber is adopted for hybrid FRP bar processed by Haerbin Polytechnic College and Haerbin Glass Fiber Reinforced Plastic Research Institute. The bundle in the middle is glass fiber. In the perighery is carbon fiber. Epoxy resin is adopted for matrix. In it, volume content of carbon fiber is 60%, glass fiber 10%, Epoxy resin 30%. Because that content of glass fiber is low, test result is close to carbon fiber performance, with not much reduce of strength. Elastic modulus reduces by about 15%. Ductility heightens about 10%. As concrete structure demands ductility design, heightening of ductility has important significance.

Hybrid effect. The rule of mixture(ROM) is normally used to evaluate mechanical property of hybrid composite material. What is called the rule of mixture is to estimate performance of hybrid material according to sum of weight composing performance of each component material. However, the rule of mixture is not accurate to evaluation of mechanical property of most hybrid composite material. Deviation of actual value of mechanical property of any hybrid composite material to estimated value of the rule of mixture is defined as “hybrid effect”. Those higher than calculated value of the rule of mixture become positive hybrid effect. Those lower than calculated value of the rule of mixture become negative hybrid effect. Hybrid effect is a kind of phenomenon especially in hybrid FRP bar. It has not only reserved advantages of simple fiber FRP bar, but also acquired more excellent comprehensive properties because of mingling of different fibers. Property of this kind of hybrid FRP bar is not algebraic sum of simple fiber bar. Hybrid effect can embody in the fields of breaking elongation, strength, energy and functional properties (such as fatigue resistance), etc. But composite material has many kinds of properties, not being possible to be all positive or negative hybrid effects. In normal circumstance, in the same time when some properties acquire positive effect while negative hybrid effects will produce in some other properties. Therefore, when conducting hybrid FRP bar design, we should make positive hybrid effects produce in required properties according to usage of FRP bar.

FRP bar used for concrete structure reinforcement mainly needs higher strength and larger ductility properties. Starting from these two points, research according to relevant hybrid fiber composite material shows that when two kinds of fibers with different tensile strain, ratio of elongation and

ultimate strain mingle, on condition that volumetric quantity of fiber with low ratio of elongation is lower than its critical volume quantity, "yield point elongation" similar to steel products will appear in stress–strain relation after the two mingling. For example, mingling CF with GF, when volumetric quantity of CF with low ratio of elongation is lower than its critical volumetric quantity, phenomenon[2] of breakdown for second time will appear for stress – strain curves of CGFRP bar. Ultimate strength is between CFRP bar and GFRP bar. Ultimate strain is not obviously lower than simple GFRP bar. And strain corresponding to first-grade breakdown (yield-like point) is obviously larger than ultimate strain of simple CFRP. This is positive hybrid effect.

The main corresponding reason to produce this positive hybrid is that when fiber bundle suffers from pulling, breakdown of fiber bundle is a course happening in succession. For simple FRP bar, defect in fiber makes those weak fibers suffering large force break down first (below 40% of ultimate strength of composite material). Suffering force by fibers redistributes. Again some weak fibers suffering large force break down in succession, until fiber bundle totally break down. When mingling to use two kinds of fibers, carbon fibers with lower ratio of elongation break first and forming crack. According to theory suppressing crack growth, glass fiber with high ratio of elongation plays the role of suppressing crack from spreading, and bearing extra load caused by breaking of carbon fibers with lower ratio of elongation. Besides, after carbon fibers break into short fibers, they can also play not a small role in rigidity and strength. Therefore, breaking strain of carbon fiber in hybrid FRP bar is improved obviously, and making strength of glass fiber exerting in hybrid FRP bar higher than simple status.

Analysis of design of CGFRP bar

If elastic modulus of carbon fiber and glass fiber are actively E_c and E_g, tensile strength respectively σ_{cfu}, σ_{gfu}, ultimate strain respectively ε_{cfu} and ε_{gfu}, critical volumetric quantity of carbon fiber and glass fiber being able to produce the above mentioned more ideal positive hybrid effect expressed by V_c and V_g, then computational expression among them are as Eq. 1.

$$\frac{V_f}{V_g} = 1 + \frac{E_g}{E_c}\left(\frac{\varepsilon_{gfu}}{\varepsilon_{cfu}} - 1\right) \tag{1}$$

In the formula: V_f=V_c+V_g, and meeting V_f+V_m=1,

V_f is total volumetric proportion of fiber, V_m is volumetric proportion of resin matrix, all are fixed value.

In the premise of V_f and V_m being all constant, when volume fraction of carbon fiber is smaller, as ε_{cfu} is small, as a result, externally exerted load concentrates on this small fraction, producing breakage rapidly. Carbon fiber after breakage occupies inefficient volume. Therefore, in a certain range, tensile strength of composite material reduces along with increase of content of carbon fiber. When reaching critical volume fraction, tensile strength also lowers to the lowest point (critical point). After then, if continuing to increase content of carbon fiber, the load is mainly borne by carbon fiber. Action of glass fiber weakens and tensile strength gradually increases. In conducting design of hybrid FRP bar, it is very important to determine critical volume of fiber first. We can conduct calculation by formula (1).

When considering V_f=1, converting formula (1), we obtain computational expression of critical volume quantity of glass fiber as Eq. 2.

$$V_g \geq V_{g\min} = \frac{\sigma_{cfu}}{\sigma_{gfu} + \sigma_{cfu} - \sigma'_g} \tag{2}$$

In the formula, σ'_g is stress level of glass fiber when carbon fiber breaking.

Mechanical property index of CGFRP

Elastic modulus . Stress – strain relation of CGFRP bar formed by mingling of carbon fiber and glass fiber assumes a state of two broken lines. Elastic modulus on the first stage can be obtained by hybrid formula as Eq. 3.

When carbon fibers with low ratio of elongation break into short fibers with critical length, CGFRP bar becomes composite material mingling with long and short fibers. Short fibers can still continue to bear part of load. Maximum average fiber stress borne by it is almost half of long fiber. When same strain produces for the two kinds of fibers, elastic modulus of short fibers of carbon fibers in CGFRP is equivalent to $E_c/2$ [1]. So, computational expression of elastic modulus of CGFRP in the second stage of suffering force is as Eq. 4.

$$E_h = E_c V_c + E_g V_g + E_m V_m \tag{3}$$

$$E_h = E_c V_c / 2 + E_g V_g + E_m V_m \tag{4}$$

Tensile strength. As CGFRP breaks in two times, if its strength in its first breaking is expressed by σ_{hf1}, multiplying the two sides of formula (3) by ε_{cfu}, and omitting $E_m V_m$ term (E_m is very small), we can obtain σ_{hf1} as Eq. 5. Breaking down for the second time, i. e. ultimate strength expression of CGFRP is as Eq. 6.

$$\sigma_{hf1} = \sigma_{cfu} V_c + \sigma' V_g \tag{5}$$

$$\sigma_{hfu} = \sigma_{cfu} V_c / 2 + \sigma_{gfu} V_g \tag{6}$$

Conclusion

(1)When mingling with two kinds of fibers with different tensile strength, different ratio of elongation and different ultimate strain, on condition that volumetric quantity of fibers with low ratio of elongation is lower than its critical volumetric quantity, "yield point elongation"similar to steel products will appear for stress – strain relation after mingling the two.

(2)By regulating volume percent of hybrid fibers, it is feasible to obtain composite material with high strength, good ductility and high performance. It can not only reduce cost, but also obtain good properties for concrete structure, supplying an efficient path for structural ductility of FRP bar concrete and guaranteeing structural safety.

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References:

[1] Huancheng Song, Zuoguang Zhang: Hybrid Fiber Composite Material, Publishing House of Beijing Aviation and Space Flight University, Beijing, 1989

[2] Weihua Shi, etc: New Type Carbon Material, 1996, 11(4), p.53-58

[3] Shuang Yang, etc: Fiber Composite Material, 2001, 14(4), p14-18

[4]Xinyue Zhang, etc: Mechanical Property and Perception Property of FRP Bar and its Concrete Component, Master thesis, Haerbin Polytechnic College, Haerbin, 2002

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