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Axial compression behavior of hybrid fiber reinforced concrete filled steel tube stub column

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HIGHLIGHTS

- Axial behavior of steel-polypropylene hybrid fiber reinforced CFST column.
- Hybrid fiber has negligible effect on failure mode and ultimate capacity.
- Hybrid fiber delays failure process and improves energy dissipation capacity.
- Fiber hybridization has favourable effect on ductility over the sum of single fibers.

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ABSTRACT

Previous studies indicate that the use of hybrid fiber has the potential to improve the properties of concrete. This paper investigates the effect of steel-polypropylene hybrid fiber on the axial compression behavior of concrete-filled steel tube (CFST) columns. Sixteen hybrid fiber reinforced concrete filled steel tube (HFRCFST) stub columns are tested under axial load. The variables considered in the tests are the steel fiber volume percentage and polypropylene fiber quality percentage. The failure mode, ultimate capacity, ductility and energy dissipation capacity of HFRCFST column are investigated. Experimental results show that hybrid fiber has negligible effect on the failure mode and ultimate capacity, delays the failure process and improves the energy dissipation capacity. The fiber hybridization has a favourable reinforcement effect on the ductility over the sum of the individual single fibers. Therefore, using hybrid fiber reinforced concrete is a more effective method to improve the ductility of the CFST columns than single fiber.

1. Introduction

In modern structural constructions, concrete-filled steel tube (CFST) columns gradually become popular due to the merits of high bearing capacity, rigidity and ductility. Those advantages are contributed by the composite action between steel tube and concrete core [1–4]: steel tube provides permanent formwork and acts as a confining jacket for the concrete core, while concrete core prevents or delays local buckling of the steel tube.

Nowadays, high strength concrete is widely used in CFST columns. The usage of high strength concrete results in smaller column size, less self weight and higher load carrying capacity without any increase in construction cost [5–7]. However, high strength concrete is brittleness and easy cracking [8,9], consequently a sharp drop of ductility is presented in the high strength concrete filled steel tube columns [10,11]. In order to improve the ductility of high strength concrete filled steel tube columns, one of the solutions is thickening the steel tube. But the thicker steel tube inevitably increases the construction cost and structural weight, which is an uneconomic choice.

Adding fibers has been proved to be an effective way to improve the ductility of concrete. The fibers can bridge the cracks of concrete and resist their propagation, thus a post-crack behavior of concrete is obtained. This technology was originally developed by Romualdi et al. [12] in 1960s. In recent years, a large amount of effort was devoted to research on fiber reinforced concrete. Various types of fibers have been studied, including metallic fibers [13–16], polymeric fibers [17–19] and natural or cellulose fibers [20,21]. It is found that single fibers only work for a particular range of strain and crack [22,23], while hybrid fibers provide crack resistance in various levels [24,25]. Hybrid fibers are a mixture of fibers with various types, sizes [40–42] and/or geometries (smooth, twisted, hooked, straight and so on) [42–44]. Micro fibers affect

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Nomenclature

SF	Steel fiber	Δ_{85}	Axial shortening of 0.85Nu
PF	Polypropylene fiber	Δ_u	Axial shortening of Nu
V_f	SF volume percentage	$\beta_{s,p}$	Reinforcement coefficient of hybrid fiber reinforced CFST column
M_f	PF quality percentage	β_s	Reinforcement coefficient of SF reinforced CFST column
D	Diameter of the steel tube	β_p	Reinforcement coefficient of PF reinforced CFST column
t	Thickness of the steel tube	α_h	Hybrid effect coefficient
L	Length of the steel tube	$N_{u,fr}$	Ultimate axial load of hybrid fiber reinforced CFST column
f_y	Yield strength of steel	$N_{u,m}$	Ultimate axial load of the corresponding PCFST column
f_{cu}	Compressive strength of concrete	$DI_{u,fr}$	Ductility index of hybrid fiber reinforced CFST column
N_u	Ultimate axial load	$DI_{u,m}$	Ductility index of the corresponding PCFST column
E	Energy dissipation capacity		
DI	Ductility index		

the formation and coalescence of micro-cracks, and macro fibers affect macro-cracks. Frequently-used hybrid fibers are steel-steel [6,25–28], steel-polymer [29–34], polymer-polymer [35–37] and steel-natural [38,39] fibers. Steel-steel fibers result in high strength and modulus [25–28], steel-polymer fibers improve the ductility and energy absorption capacity without increasing the self weight significantly [22], polymer-polymer fibers is an economic way to improve the ductility, and the positive synergy of steel-natural fibers can improve the toughness of concrete [39].

In the field of hybrid reinforcement, steel-polymer fibers attract much more researchers' attention. Many studies [22,50] demonstrate that the incorporation of steel and polymer fibers can enhance toughness and ductility of concrete materials. The crack mechanism is modified by the combination of steel and polymer fibers during the initiation, propagation and coalescence of cracks [34,51,52]. Hybridization of steel fibers with polymer fibers can result in significantly enhanced flexural behavior and tensile property, but the increment is related to the fiber content, shape and length [53–55]. The incorporation of steel-polymer hybrid fibers is found as an effective way to improve the bond performance between rebar and concrete due to their effect inhibiting initiation and propagation of cracks [56,57]. In chloride environment, steel-polymer hybrid fibers can delay the corrosion initiation of rebar due to the high propensity for crack resistance [58,59].

At present, the available studies are primarily limited to use the hybrid fibers in improving the properties of concrete targets. Limited researches focus on the hybrid effect on the mechanical properties of structural elements. Almusallam et al. [60] confirmed the significant effect of hybrid-fibers in improving the impact resistance of RC slabs/plates. Ding et al. [61] reported that hybrid fibers can evidently enhance both the shear strength and shear toughness of RC beams. Ganesan et al. [62] carried out experimental investigation and draw a conclusion that addition of fibers in hybrid form can improve the engineering properties of concrete beam column joints subjected to reverse cyclic loads. Dazio et al. [63] studied the nonlinear cyclic behavior of hybrid fiber concrete structural walls, and revealed that the proposed structural system has a larger inelastic deformation capacity than conventional reinforced concrete structure. Most attempts have been made to study the hybrid effect on RC structures, no available literature concerns on the behavior of hybrid fiber reinforced concrete filled steel tube column.

This paper studies the use of the steel-polypropylene hybrid fiber to improve the axial compression behavior of CFST columns. Sixteen mixtures with variable steel fiber volume percentage and polypropylene fiber quality percentage are filled into welded circular steel tubes to investigate the axial compression behavior of hybrid fiber reinforced concrete filled steel tube (HFRCFST) columns. Failure mode, ultimate capacity, ductility and energy dissipation capacity of the HFRCFST columns are investigated.

2. Experimental program

2.1. Materials

In order to explore the effect of fiber hybridization on the properties of concrete, two types of fibers, steel fibers (SF) and polypropylene fibers (PF), are used in the investigation. SF has the shape of hooked-end, and PF is straight. Table 1 shows the properties of those two fibers. The Portland cement type I (CEM-I 42.5N) with a specific density of 3.06 kg/m^3 and a specific surface area of 301 m^2/kg is used in the mixture (specific surface area is defined as the total surface area of a material per unit of mass). Silica fume is adopted to increase the strength of the concrete mixture by filling the voids created by free water in the matrix. Silica fume has an average particle size of 0.1–0.2 μm. The chemical compositions of Portland cement and silica fume are listed in Table 2. Fine aggregate is the river sand with the grain size of 2.5 mm. Coarse aggregate uses the granite stone with particle size of 5–10 mm. Fly ash is used as a filler to improve the flowability. Moreover, a polycarboxylate-based superplasticizer is also added to ensure the workability of concrete mixture.

2.2. Mixing design

A total of sixteen mixtures are designed to investigate the properties of hybrid fiber reinforced concrete (HFRC), including one without any fiber, six with single type fiber (including single steel fiber and single polypropylene fiber) and nine with hybrid fiber. All the fiber reinforced concrete mixtures have the same mixture proportions with the plain concrete, except the proportions of fibers. The plain concrete is designed to have the compressive strength of 50 MPa. The water to binder ratio is held constant at 0.38. According to the Ref. [45], the addition of steel fibers with volume percentage higher than 2% may result in sharp drop of concrete flowability. On the other hand, the influence of steel fibers with volume percentage lower than 0.5% is inconspicuous. Therefore, the volume percentages of steel fiber are set as 0%, 0.6%, 0.9% and 1.2%. The quality percentage of polypropylene fiber is designed as 0%, 0.6%, 0.9% and 1.2%. All chemical compositions of the mixtures are listed in Table 3. Each mixture has an individual designation as: S-X-P-Y, where "X" stands for the volume percentage of steel fiber and "Y" represents the quality percentage of polypropylene fiber.