EXPERIMENTAL RESEARCH ON THE INTERFACIAL PROPERTIES OF NON-STEAM-CURED UHPC-STEEL COMPOSITE BEAM

Wang Zhe (1), Fan Jiansheng (1), Sun Qili (1) and Liu Cheng(1)

(1) Department of civil engineering, Tsinghua University, China

Abstract

Ultra-high performance concrete (UHPC) is a material with high strength, high toughness and good durability. It can be used to replace normal concrete in steel-concrete composite beams to reduce the section size and dead weight of the beams. The interfacial properties between UHPC and steel are different from that between normal concrete and steel and they can be improved by some interface treatments. It is possible to reduce or replace the use of stud connectors by some interface treatments, with enough shear and uplift capacity of the interface. In this paper, two tests of non-steam-cured UHPC-steel composite beams with different interface treatments were conducted to investigate the interfacial properties between UHPC and steel. The interface treatment included headed studs connecting and epoxy based adhesive with sprinkled-in aggregates. The results showed that the composite beam treated by epoxy based adhesive with sprinkled-in aggregates behaved well compared with the composite beam using headed studs connecting.

Résumé

Le béton fibré à ultra-hautes performances (BFUP) est un matériau avec une grande résistance, une ténacité élevée et une bonne durabilité. Il peut être utilisé pour remplacer le béton normal dans des poutres mixtes acier/béton pour réduire la taille des sections et le poids propre des poutres. Les propriétés d'interface entre le BFUP et l'acier sont différentes de celles entre le béton normal et l'acier et peuvent être améliorées par des traitements. Il est possible de réduire ou de remplacer l'utilisation de goujons par des traitements assurant une capacité suffisante vis-à-vis du cisaillement et du soulèvement. Dans cet article, deux essais de poutres mixtes acier-BFUP non traité thermiquement avec des traitements d'interface différents ont été conduits pour examiner les propriétés d'interface entre le BFUP et l'acier. Les traitements d'interface consistaient en une connexion par goujons et une connexion adhérente à base de résine époxy gravillonnée. Les résultats ont montré que la poutre mixte traitée avec résine époxy gravillonnée s'est bien comportée par rapport à la poutre mixte utilisant la connexion par goujons.

1. INTRODUCTION

UHPC is a cement-based composite material with excellent gradation. It has high strength, toughness and durability. As a cement-based composite material, UHPC makes a great improvement of material properties. In early years, it was used to repair and reinforce the bridge deck, pile foundation, sewage pipes and hydraulic structure etc. In the new century, UHPC showed its advantages as structural materials and it has been applied in highway, bridges, subway and civil air defence projects [1-2]. However, most of UHPC needs steam cure, so its engineering application is very limited. Non-steam-cured UHPC can break these restrictions, and it is suitable for more engineering conditions [3-4].

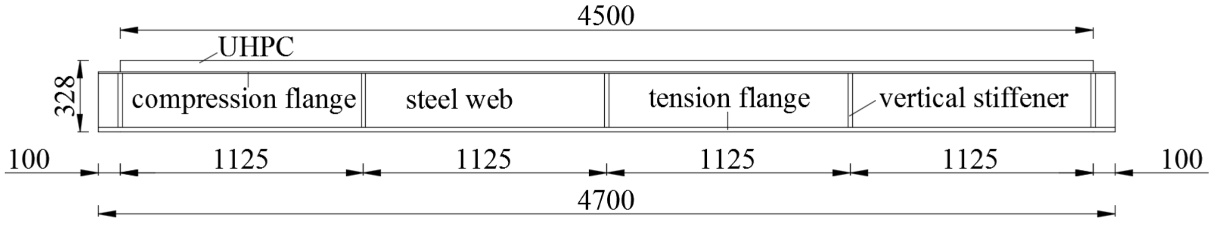
Steel-concrete composite beams have the advantages of light weight and small section size. They are widely used in structural engineering. The bond strength between normal concrete and steel plate is low, so it is necessary to set shear connector at the interface between concrete and steel plate to take full use of the two materials. The bonding performance between UHPC and normal concrete is good [5]. And the bonding strength between UHPC and rebar is much higher than that between normal concrete and rebar [6]. Therefore, as a new type of composite structure, the non-steam-cured UHPC-steel composite beam is expected to reduce the use of shear connector and improve construction convenience.

In this paper, the early strength and low shrinkage UHPC was prepared by high strength grouting material and steel fibre. Two non-steam-cured UHPC-steel composite beams with different interface treatments were designed to investigate the interfacial properties between UHPC and steel.

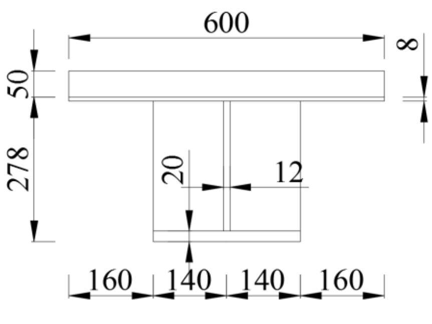
2. EXPERIMENTAL PROGRAM

2.1 Details of beam models

In this paper two non-steam-cured UHPC-steel composite beams were designed, numbered Beam 1 and Beam 2. Details of the beams are shown in Figure 1.



(a) elevation



(b) cross section

Figure 1: Details of beams: elevation and cross section of Beam 1 and Beam 2 (Unit: mm)

2.2 Interface treatment

Two different interface treatments were used in this paper. Beam 1 was treated by epoxy based adhesive with sprinkled-in limestone aggregates (Figure 2). Beam 2 used headed studs connecting.

The epoxy based adhesive used in this research was mixed by WSR-618 epoxy resin produced by Nantong Xingchen Synthetic Material Co., Ltd. and TY-651 low molecular weight amilan polyamide resin produced by Tianjin Yanhai Chemical Co., Ltd. with a volume ratio of 3: 2.

Figure 2: Interface treatment of Beam 1

2.3 Loading method and instrumentation

The two beams were simply supported. They were loaded with a point load at midspan, using a 1,000 kN compression-testing machine, as shown in Figure 3. The shear span ratio is 6.86. Vertical stiffeners were designed at the supports and the loading points to prevent local buckling of the steel web before interfacial failure. The interfacial slip and uplift, and flexural cracks were measured at every load increment of 50 kN.

Figure 3: Test setup for beams

2.4 Material properties

The UHPC was mixed consisting of sulphate aluminium cement and shrinkage reducer. The steel fibre was 13 mm long and its diameter was 0.2 mm. The volume ratio of steel fibre was 2 % and the mix proportion is shown in Table 1.

Table 1: Mix proportion

Component	Unit	Amount
Sulphate aluminium cement	kg/m^3	1022
Mineral admixture	kg/m^3	147
Quartz sand	kg/m^3	886
Suspending agent	kg/m^3	73.8
Superplasticizer	kg/m^3	5.7
Additive (shrinkage reducer, defoamer etc.)	kg/m^3	13
Water	kg/m^3	215
Steel fiber	kg/m^3	156

The UHPC strength f_c of the deck was evaluated using 100 mm × 100 mm ×100 mm cubes. The UHPC cubes and the corresponding test beams were cured under similar conditions. The material properties are given in Table 2.

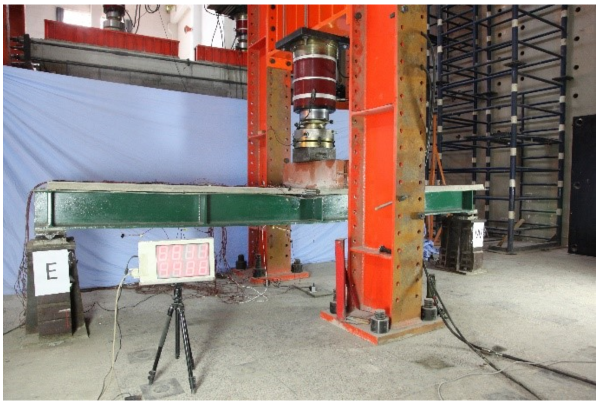
Table 2: Material properties

	Applications	Thickness (mm)	f_y (MPa)	f_{su} (MPa)
Steel plate	Compression flange	8	346.5	488.5
	Web	12	353.2	500.5
	Tension flange	20	349.5	541.6
UHPC	f_c (MPa)		E_c (GPa)	
	119.3		40.6	
Headed stud	Diameter (mm)		f_u (MPa)	
	13		528.3	

3. BEHAVIOUR OF TEST BEAMS AND RESULTS

3.1 Beam 1

Figure 4 shows that Beam 1 failed in horizontal shear when the load reached 680 kN. Large slip and separation occurred at its interface along half of the beam. Flexural cracks occurred at the bottom of the UHPC decks and local buckling occurred at the top flange of the steel beam after the sudden separation. Initially, there was no slip in the Beam 1. At failure, the entire UHPC deck on the weaker half sheared suddenly along the interface with a large slip, as shown in Figure 6(a).



(a)

(b)

(c)

(d)

Figure 4: Details of failure of Beam 1

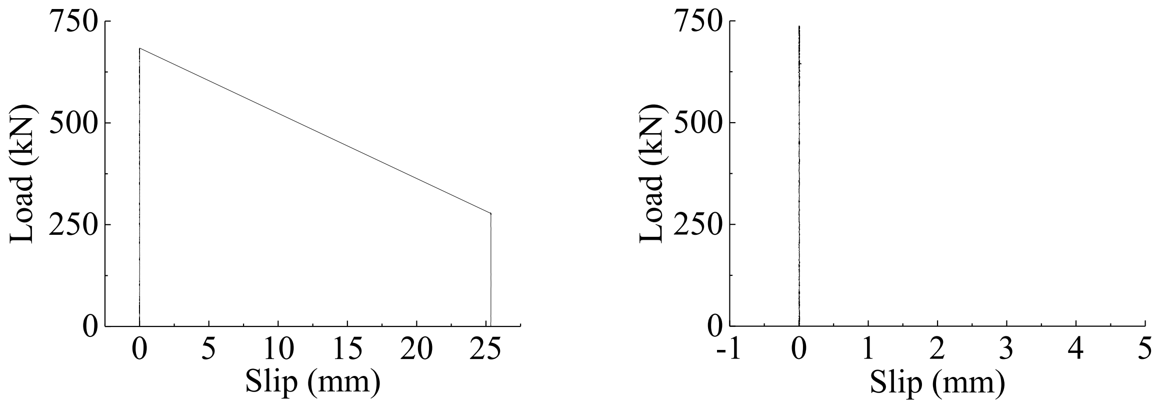
3.2 Beam 2

Figure 5 shows that Beam 2 failed in flexure at 737 kN because the interfacial shear and uplift capacity is sufficient to prevent horizontal shear failure. The UHPC deck and steel beam was integrated to bear the bending moment until the top of the UHPC deck crushed. After that, local buckling occurred at the top flange of the steel beam because of the large compression stress. There was no slip along the interface in Beam 2, as shown in Figure 6(b).

(a)

(b)

Figure 5: Details of failure of Beam 2



(a) Slip curve of Beam 1 (b) Slip curve of Beam 2

Figure 6: Slip curves

3.3 Computation of horizontal shear stress

Equilibrium method was used to compute the horizontal shear stress as Clause 16.4.5.1 of the ACI 318M-14 mentioned that "factored horizontal shear shall be calculated from the change in flexural compressive or tensile force in any segment of the composite concrete member". This relationship can be expressed as:

$$\tau = \frac{T}{bl} \tag{1}$$

where:

T = total tension in the steel beam
b = width of interface
l = length over which horizontal shear is to be transferred

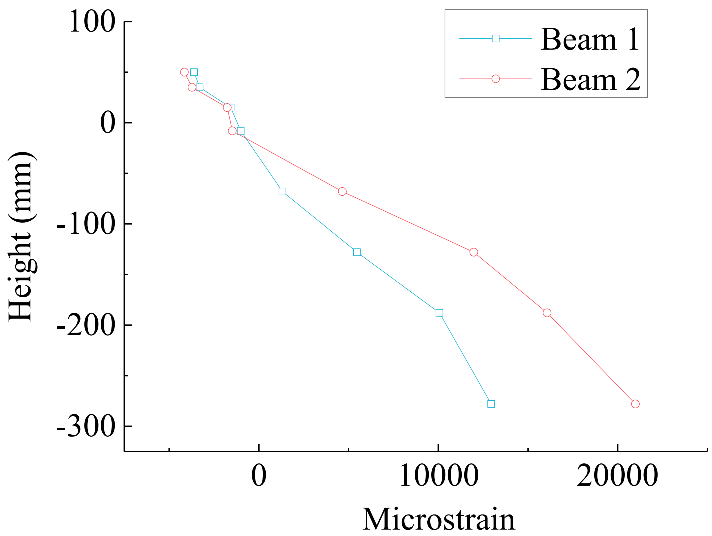


Figure 7: Strain distribution

Figure 7 shows the strain distribution at the mid-span section before failure (the height of the interface is 0). The strains between the measuring points are supposed to be linear. The stress distribution at the mid-span section can be obtained by the stress-strain curves from material test. T_1 in Beam 1 is 1648 kN and T_2 in Beam 2 is 1883 kN. So the horizontal shear stress τ_1 in Beam 1 is 1.220MPa and the horizontal shear stress τ_2 in Beam 2 is 1.395 MPa.

Beam 1 failed in horizontal shear so the horizontal shear strength v_1 of the interface treated by epoxy based adhesive with sprinkled-in limestone aggregates is 1.220MPa in this condition. The design shear strength N_v^c of a single headed stud can be:

$$N_v^c = 0.43A_s\sqrt{E_c f_c} \tag{2}$$

or

$$N_v^c = 0.7A_s f_u \tag{3}$$

whichever is smaller, where:

A_s = cross-sectional area of a single stud
E_c = Young modulus of UHPC
f_c = compressive strength of UHPC
f_u = ultimate tensile strength of stud

$$N_v^c = 0.43A_s\sqrt{E_c f_c} = 0.43\pi\times\left(\frac{13}{2}\right)^2\times\sqrt{40600\times119.3} = 125.61\text{kN} \tag{4}$$

$$N_v^c = 0.7A_s f_u = 0.7\pi\times\left(\frac{13}{2}\right)^2\times528.3 = 49.01\text{kN} \tag{5}$$

so N_v^c is 49.01kN.

The horizontal shear strength v_2 of the Beam 2's interface can be:

$$v_2 = \frac{nN_v^c}{bL} \tag{6}$$

where:

n = number of studs in the interface
L = length of contact surface

so $v_2 = \dfrac{90\times49.01}{600\times4500} = 1.63\text{MPa} > \tau_2$. This result proves that Beam 2 didn't fail in horizontal shear.

4. CONCLUSIONS

- The early strength and low shrinkage UHPC without steam curing shows good properties in the beam tests.
- The interface treated by epoxy based adhesive with sprinkled-in limestone aggregates performed well in the beam test. The ultimate load of Beam 1 is 92.3% of the ultimate load of Beam 2 which is fully connected.
- The value of the horizontal shear stress at failure in Beam 1 is 87.5% of that in Beam 2. The result indicates that the interface treatment using epoxy based adhesive with

sprinkled-in limestone aggregates can take place of the interface treatment using headed studs under some condition.

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