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COMPOSITE STEEL AND RPC TESTING

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Abstract: Reactive powder concretes are a set of ultrahigh-strength concrete reinforced with fibers. Their compressive strength is greater than 100 MPa. For assuring connection of steel beams and a concrete slab, steel stud connectors are used. The investigation of that kind of shear connection efficiency, in the case of this higher strength concrete deck using standard push-out test specimens has been executed. The experimental results are presented in the paper.

Keywords: Push-out test, Reactive powder concretes, Composite structure, Shear connection

1. Introduction

Technology advancement in concrete industry and expanding interest for great quality construction materials has encouraged the development of higher performance concrete. Despite of many advantages gained using this performance-based concrete, however, conventional ultra-high performance concrete process raises many concerns. Especially on sustainability issues and often the compositions are not optimized. Reactive Powder Concrete (RPC) may be one of promising unconventional construction materials due to its high strength, toughness, durability and high crack resistance. The superior mechanical and material properties of RPC are extremely attractive to structural engineers to apply them in infrastructures for enhancing their resistance under severe environments and loads.

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Potential use of the RPC to attach precast concrete decks to steel superstructure is studied in the paper. The shear capacity and the load-slip relations are the most important characteristics for the design of this type of composite structures. The suitable method to found the shear connection properties could be full-scale composite beam tests, but quite a time-consuming and rather costly [1]. Therefore push-out test were implemented in the research [2]. During this experimental investigation, the local shear force has been applied to a concrete specimen. The transfer of the resulting shear force between the steel section and concrete slabs was provided by shear studs.

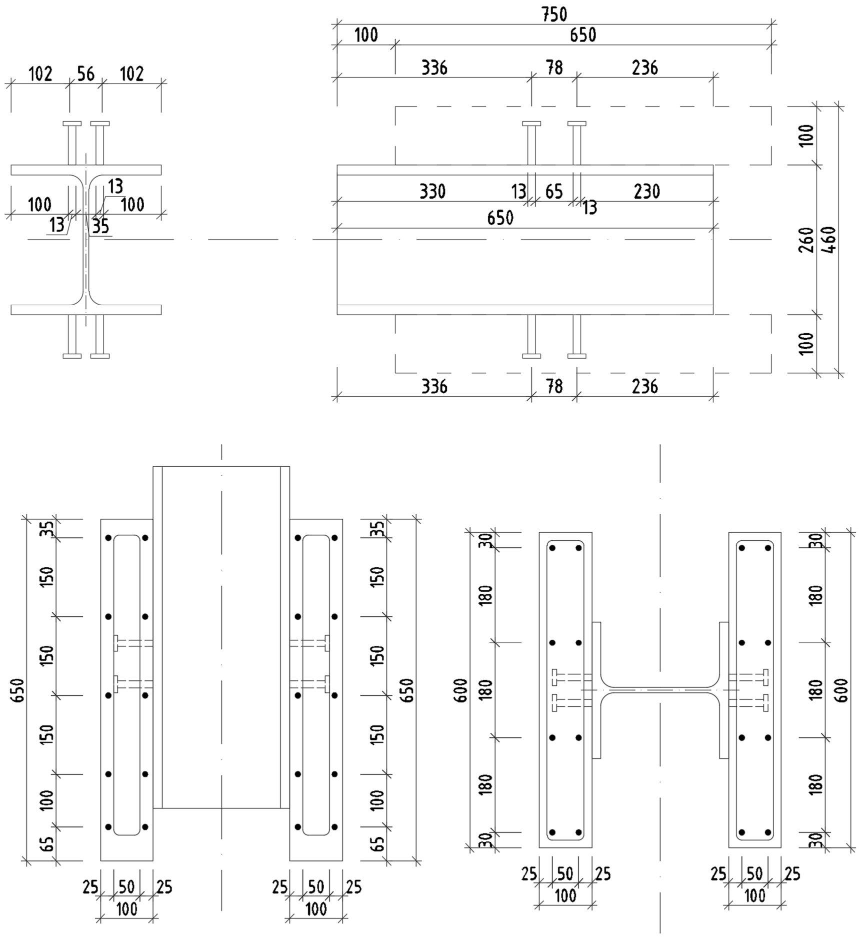
2. Properties of tested material

Optimization of the concrete composition can be alternatively performed without additional coarse aggregate. Improved homogeneity and compactness of the RPC material is instead achieved through the ideal grading by adding silica fume, quartz and sand powder. Microfibers are also added to improve ductility. By using super-plasticizers, it is possible to reduce the water and cementations ratio. These supplementary binder materials result also to the low Water to Binder ratio (W/B), effecting that only portion of cement can hydrate in RPC. Besides reducing the W/B, incorporation of ultrafine particles would also benefit the early strength development of the concrete. These particles will act as nuclei for cement to accelerate the hydration process, to reduce permeability and to densify the microstructure by filling up voids between cement grains. The combination between fibers and ultrafine particles can closely assure the hydration product and accelerates the pozzolanic reaction improving its strength and the rheological characteristics. Another important effect is the improvement of the interfacial transition zones between binder and fibers which increases the mechanical strength and enhances the microstructure. The only issue faced when incorporating conventional steel fibers in the concrete is their high price. Attentions have been given in search of substituting steel fibers and part of cement to produce RPC with less cost and while providing the equivalent properties. Available in sufficient quantities with very low cost, basalt fiber is gaining its reputation as the best option to replace steel fibers in RPC.

The experimental work consisted of mixing, casting and testing the mechanical properties of ordinary and high-strength concrete. A 50-L pan mixer was used to prepare fresh RPC in this study. All concrete mixes were prepared for about 20 minutes. After casting was completed, samples were well covered by plastic sheet. Samples were then demolded after 24 hours and shifted to drying shelves for ambient curing until the specified testing time, commonly 28 days. Modified polycarboxylic ether based super-plasticizers were selected and used in all mixes. RPC with compressive strength of up to 120 MPa at 28 days was successfully prepared without special curing treatment using combinations of fibers and by incorporating higher content of supplementary binding materials. Consequently thus, three sets of specimens for mechanical properties testing were prepared to determine the compressive and flexural strength as well as elastic modulus of ordinary concrete but also RPC with addition of steel or basalt fibers. Thus, the investigation included entirely 6 cubes of size 150 mm, 6 cylinders (150x300 mm) and 6 beams (150x150x600 mm). The tests were conducted in accordance with the respective standard procedures.

3. Push-out test specimens

The configuration of this push-out investigation was in accordance with Eurocode 4 [3] and [4]. Two test specimens of the ordinary low-strength concrete C1 and C2, shown in *Fig. 1*, consisted of a steel beam HEB 260B, two concrete slabs from normal low-strength class of C25/30 attached to the flanges of the steel beam. With dimensions of 650 mm long, 600 mm wide and four stud connectors attached to each flange with a shank diameter of 16 mm and 75 mm in height. The longitudinal distance between the connectors was 96 mm and transversal pitch 56 mm.



C1,

C2,

Fig. 1. Push-out specimen C1 and C2

Two next sets of the specimens *S1*, *S2* and *B1*, *B2* consisted also of steel profile HE 260B and two precast concrete slabs of identical dimensions of 600x650 mm and thickness of 100 mm. As it can be seen in the *Fig. 2*, in the space of future connection provided by shear studs, rectangular openings were reserved. Shear connection was completed by casting and filling in the square holes with RPC mortar of compressive strength of 120 MPa. In the case of specimens *S1* and *S2*, the RPC mortar was added a blend of 25% volume fraction of micro smooth steel fiber 12 mm length and 0.175 mm in diameter. While specimens *B1* and *B2* were prepared with the addition of basalt fibers 12 mm long and only 18 μm in diameter.

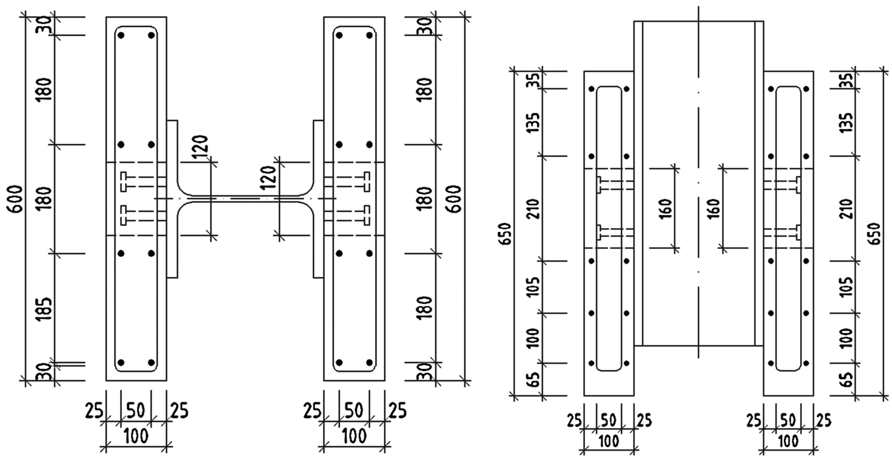


Fig. 2. Push-out specimen S1 - S2 and B1- B2

4. Experimental results

The slabs are bedded down directly onto the reaction floor with load being applied to the upper end of the member. All tests were conducted using a universal testing machine, as shown in *Fig. 3*. The load was applied in increments of 20 kN from 0 to 160 kN (40% of the expected failure load), then returned to 40 kN (5% of the expected failure load). After the loading cycle between 40 kN and 200 kN was repeated 25 times. The displacement controlled load continued up to the failure at the speed of 1 mm in 2 minutes. At each load or displacement increments, the slip history between two concrete slabs and the steel beam was measured by linear variable transformers and recorded. Its average value was plotted against the load per connector.

During 25 cycles (between 40 kN et 200 kN), both specimens *C1* and *C2* stayed in good condition, the slabs and the steel beam worked well together, the cracks had not yet been developed at that time. At the end of the 25th cycle loading was changed from load control to slip control. At the load of 300 kN, the interface between steel and concrete was delaminated and the slip of 0.4 mm was achieved. Beyond the load of 400 kN, the cracks began to appear in the slabs. The test was ended with the shear of the connectors at the load of 543 kN and the ultimate slip value of 3 mm, as it is illustrated in *Fig. 4*.

Fig. 3. Specimen in testing machine and ultimate failure cracking

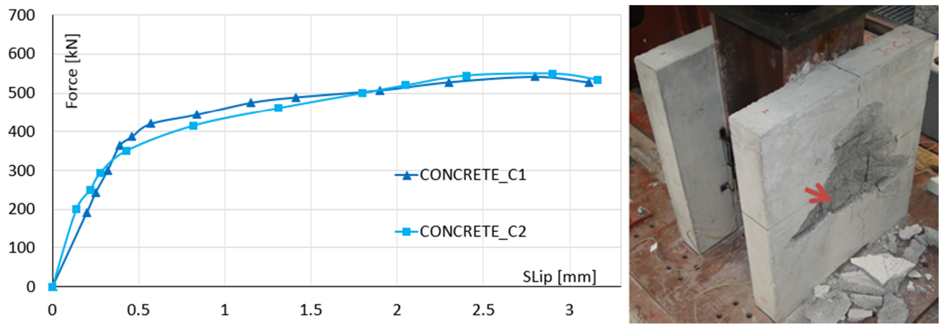


Fig. 4. Load-slip curves of the ordinary concrete specimens and failure mode

The failure of the second sets of four RPC specimen occurred by cracking of surrounding low-strength normal concrete with shear of the connectors at the ultimate load about 41% superior. The corresponding history of loading and slip development is slight different as demonstrated in *Fig. 5,* including rather changed failure mode.

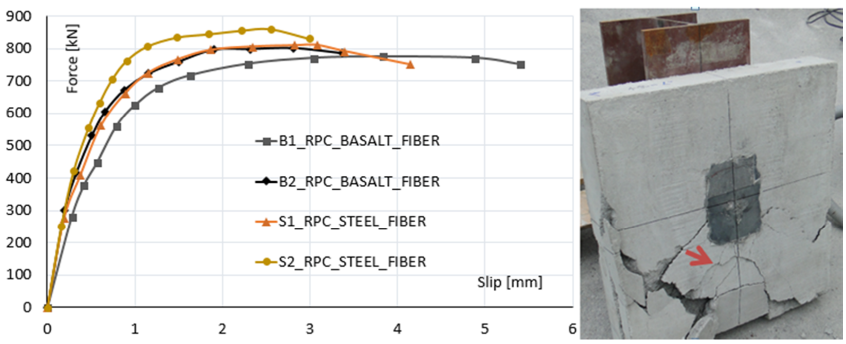


Fig. 5. Load-slip curves of the RPC specimens and failure mode

5. Conclusion

In this study, two reactive powders concrete reinforced with the steel or basalt fibers were evaluated for structural applications. Load versus strain responses under push-out testing revealed higher mechanical and cracking resistances of RPC used for shear connection of precast structural elements in comparison with normal low-strength concrete. Executed push-out specimen testing proved to describe suitably shear connection behavior as well as the resistance of shear studs and concrete slab. Also, the RPC aggregates can meet the requirements for compressive strength and other mechanical properties for use in structural applications after being cured in the conventional condition.

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