Experimental Tests of the Blast Resistance on UHPFRC and NSC Elements

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Abstract:

The resistance of the material to the effects of explosions is a very current issue. Concrete of normal strengths is subject to significant damage and collapse, which must be prevented by the design of reinforcement. The explosion causes extreme local loading, which is difficult to predict, and the reinforcement need to be dimensioned complexly. By using UHPFRC material reinforced with scattered reinforcement in the form of steel wires, the reinforcement is evenly distributed throughout the entire volume of the sample or construction. In the case of a combination of such a material with steel in the sense of connected constructions, there is a suitable use of both materials, a spread of stress and an overall greater resistance. The paper describes experimental tests of various types of UHPFRC and NSC – steel composite structures and describes their resistance to explosion.

Keywords:

Ultra-high performance fibre-reinforced concrete, normal strength concrete, blast resistance, steel-concrete composite, material

1. Introduction

Blast loading presents a sudden release of energy that must be absorbed or transferred by building structures near the explosion. Blast event can be a result of an accident or act of terrorism, which the blast loading and blast resistance of buildings is meanwhile mostly discussed in connection with. The probability of terrorist attacks in the developed countries is increasing. Globally, most of the attacks is performed by explosives, approximately 60 %. Blast can act at all possible types of building structures; therefore, the performance of steel-concrete composite structures subjected to blast loading gains great importance as a topic of research. Special attention is paid to UHPFRC. The behavior of UHPFRC structures subjected to blast overpressure and projectile loading has not been properly quantified yet and represents a very actual topic. Its mechanical properties and processability make it possible to design newly various structures with specific parameters and shapes. At the same time, a principal characteristic for practical use is its very high durability several times exceeding ordinary concrete. Methodologies for larger dissemination of possibilities of designing and applications of UHPC and UHPFRC in the Czech Republic have been drawn up under the Klokner Institute's leadership.

The paper describes experimental testing of various types of UHPFRC and NSC – steel composite structures subjected to blast loading with respect to internal blast overpressure wave propagation causing delamination at pre-defined boundaries. Experiments were focused on quantification of the effect of the ways of assuring the composite action and concrete type on the blast response of the steel-concrete composite structure. Experimental tests build on already by the authors performed numerical experiments.

2. Experimental Program

The emphasis of this part of experimental program was focused on different ways of assuring the composite action of steel and concrete subjected to blast loading. The experimental program was carried out at the Klokner Institute**.**

2.1. Experimental Specimens

The emphasis of the experimental program was focused on different ways of assuring the composite action of steel and concrete. Based on updated literature overview several ways of assuring composite action were chosen. For the chosen composite actions, it was decided to compare the performance of normal strength concrete (NSC) and ultra-high-performance fibre-concrete (UHPFRC).

The dimensions of experimental specimens were chosen 1.0x1.0x0.15m and they were constant for all the specimens. The chosen dimensions enable the use of conventional reinforcement, bolts, shear studs and shear plates. To fulfil provisions of standards on steel-concrete composite structures (EN 1994) also mild steel reinforcement of specimens were used.

The concrete mixture and its material properties was optimized to perform properly in combination with the shear connectors, and the usual fibre dimensions in UHPRFRC mixture were reduced.

The blast performance of the specimens was pre-assessed on simplified numerical models to estimate the response to blast load and minimize the risk of any adverse effects of specimen size and experiment arrangement. List of prepared specimens and their properties are shown in the following table. The specimens 1.0 to 1.5 and 2.0 to 2.5 were designed identically and the only difference was concrete type (NSC or UHPFRC).

Specimen Nr.		**Specimen description**
NSC	**UHPFRC**	
1.0	2.0	Reinforced concrete mesh Ø8/150/150, 30mm cover
1.1	2.1	Plain concrete with steel plate connected by 4pcs studs Ø10/100 in the corners
1.2	2.2	Plain concrete sandwiched in steel plates connected by 4pcs bars M10 in the corners
1.3	2.3	Plain concrete sandwiched in steel plates connected by 24pcs bars M10
1.4	2.4	Concrete with steel plate connected by 24pcs shear studs Ø10/100 to ensure composite action, additional reinforcement mesh Ø8/150/150,
1.5	2.5	Concrete with steel plate connected by 6pcs of 5mm thick shear plate to ensure composite action, additional reinforcement mesh Ø 8/150/150

Table 1. List of prepared specimens and their properties

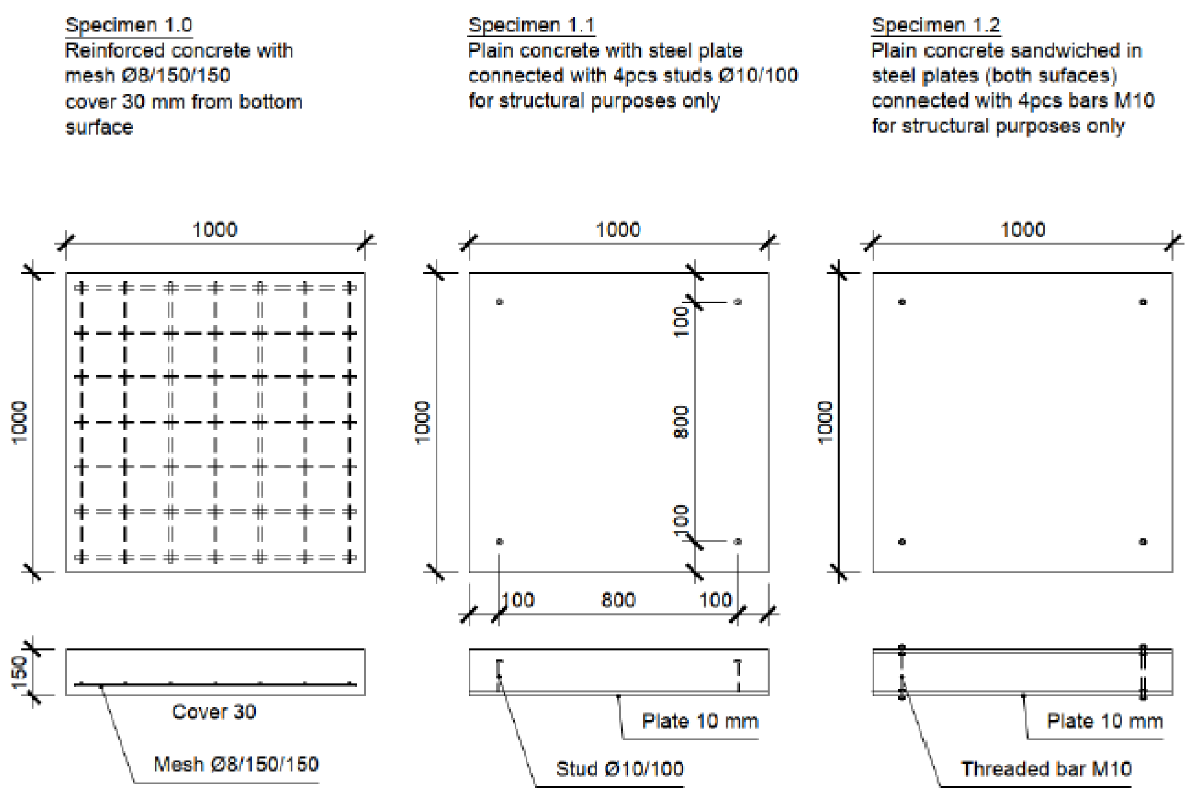

Figure 1. Detailed description of the specimens 1.0 to 1.2 (2.0 to 2.2)

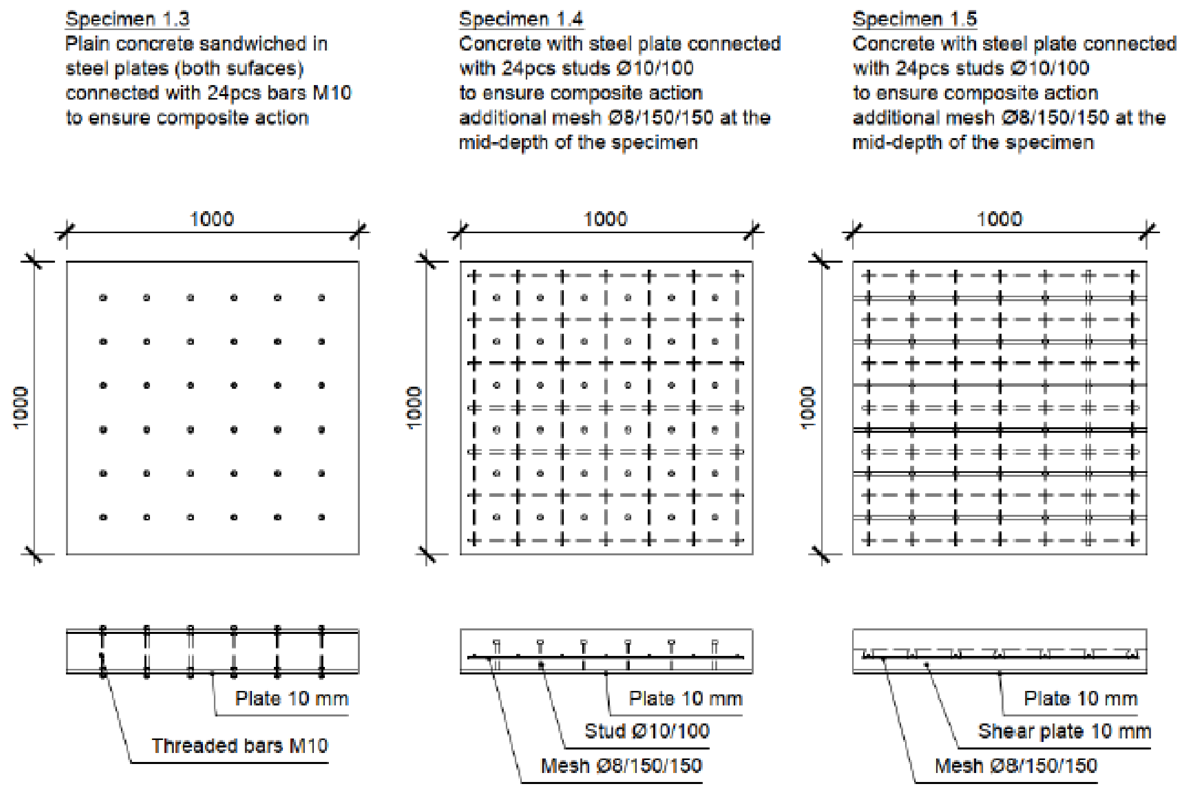

Figure 2. Detailed description of the specimens 1.3 to 1.5 (2.3 to 2.5)

The concrete mixture optimization, material properties tests and casting of experimental composite steel – concrete slab samples, was carried out in the laboratories of Klokner Institute (KI).

2.1.1. Material Properties

As it was written in text above, it was decided to compare the performance of normal strength concrete (NSC) and ultra-high performance fiber-reinforced concrete (UHPFRC). Therefore, two different mixtures of concrete were optimized for this project.

During casting process large sets of accompanying molds were produced. Samples were de-molded second day after casting and placed into water at temperature of 20±2 °C until the tests. Part of material tests on samples were performed in 28 days after the casting and part of tests were performed at the same time as the main experimental explosive tests.

The concrete mixture for NSC was C 30/37, XF2 (F.1.1), S4, D_{max} 16, CEM I 42,5, R, Cl 0,2. This mixture was chosen based on previous experimental program. Main material properties of the applied mixture determined by accompanying tests on test samples after 28 days were, as follows: the density was at the level of 2360 kg/m^3, compressive strength 39,4 MPa (cylinder 100/200 mm), modulus of elasticity 33,3 GPa (cylinder 150/300 mm) and flexural strength 3,40 MPa (beam 150/150/700 mm).

The UHPFRC mixture was developed for purpose of the intended explosive tests. The mixture was based on previously developed mixes by KI. Main characteristics of the mixture are very low water cement ratio, self-compacting character and very high material properties such a compressive strength, flexural strength and durability. Mixture was reinforced by scattered reinforcement – steel fibers in volume of 1,5%. Main material properties of the applied mixture after 28 days were, as follows: the density was at the level of 2420 kg/m^3, compressive strength 132,2 MPa (cylinder 100/200 mm), modulus of elasticity 44,9 GPa (cylinder 150/300 mm) and flexural strength 17,30 MPa (beam 150/150/700 mm).

2.1.2. Production of the Experimental specimens

The formwork was prepared in the KI laboratories. Wooden boards were used in the main formwork structure. The entire structure was strengthened by wooden prisms and connecting material. Steel plates as parts of final composite specimen with additional reinforcement were placed into the formwork and fixed on both sides. Specimens were cast in vertical position. The NSC specimens were compacted using an immersion vibrator (NSC). Compacting of the UHPFRC specimens was not necessary due to self-compacting character of the mixture.

The specimens from NSC were cast from one batch mixed by concrete plant and transported by car mixer to KI. The UHPFRC specimens were cast from 6 batches mixes by KI laboratories. All dry components of the mixture were premixed and placed into the bags. This pre-preparation made it possible to speed up the whole mixing process.

After casting, the formwork was covered by wet blankets and plastic foil. The samples were treated by water during at first two day after casting. After about a week, the main formwork was disassembled, and specimens were de-molded. No significant problems such as nests or surface flaws were observed. The specimens were transported to University of Pardubice to undertake the explosive tests.

2.2. Experimental Tests

The experimental program was performed at the premises of University of Pardubice, institute of Energetic Materials.

The specimens were located on steel frames developed and fabricated during the preceding research projects. The blast loading was constant throughout all specimen. All samples were loaded with a contact explosion of 0.5 kg of Semtex 1A. Charge was placed in the middle of the topside of each specimen. To measure blast performance of each specimen, the time history of displacement of each specimen soffit was recorded with the use of 4 channels of photonic-doppler velocimetry (PDV). Measured data will be used for further evaluation. Experiment set-up is shown in Fig. 3.

After the explosive tests was performed, the specimens were subjected to examination. Both topside and soffit of the specimens were inspected and visible damage of the specimens such as puncture into concrete and crack development of concrete encased between the steel slabs were documented.

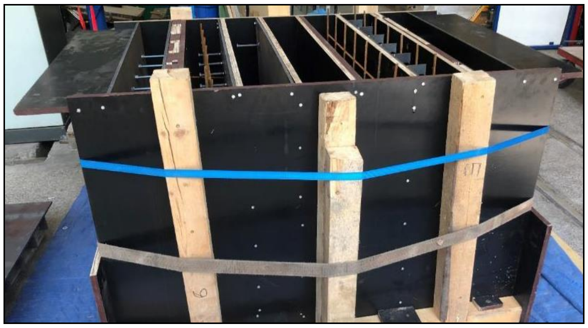

Figure 3. Framework before concrete casting

Figure 4. Experimental set-up

3. Results

The basic learning acquired from the observation is the fact that the specimens made from UHPC showed significantly less damage then the NSC specimens. This can be well observed on test specimens 1.0 and 2.0, where no steel plate was used. The NSC specimen (1.1) was completely breached, while the specimen 2.1 only experienced crater on the top and spalling on the soffit.

In the case of specimens with steel place on the soffit, tests showed the positive effect of the shear connectors are for assuring the composite action. It can be observed on the results of the specimens 1.1 and 1.4. The steel plate of the specimen was connected to the concrete with only 4 pcs of studs. In the specimen 1.4 composite action was assured by 24 pcs of studs. The concrete part of the specimen 1.1 completely lost its integrity, while the specimen 1.4 experienced only crater on the top. The UHPFRC versions of these specimens experienced significantly less damage.

The specimens 1.2, 1.3, 2.2 and 2.3, which were made from plain concrete sandwiched in steel plates, experienced only puncture in the top steel slab. No visual damage of the soffit was observed. Differences between two materials are shown in following pictures.

Figure 5. Topside of specimen No. 1.0

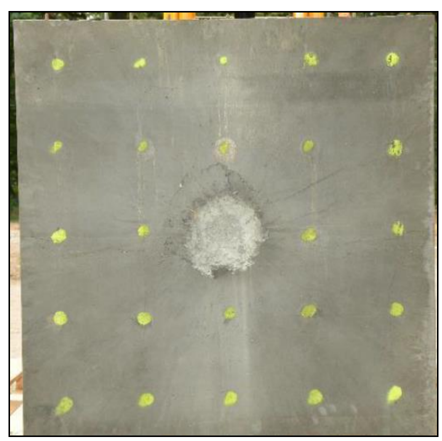

Figure 6. Topside of specimen No. 2.0

Figure 7. Topside of specimen No. 1.1

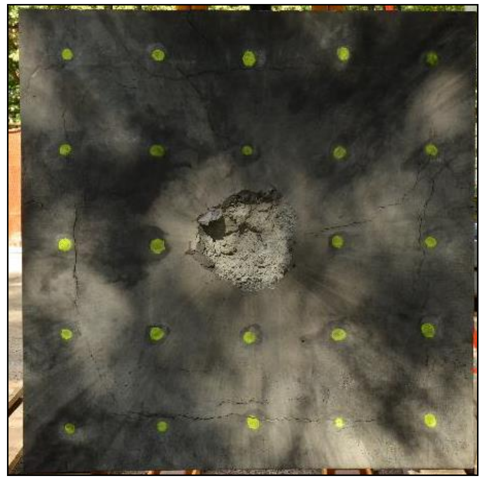

Figure 8. Topside of specimen No. 2.1

Figure 9. Topside of specimen No. 1.4

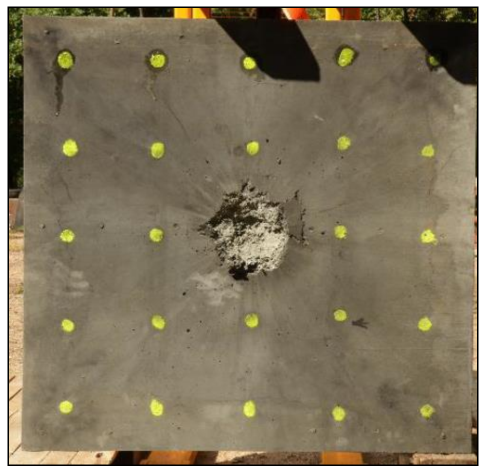

Figure 10. Topside of specimen No. 2.4

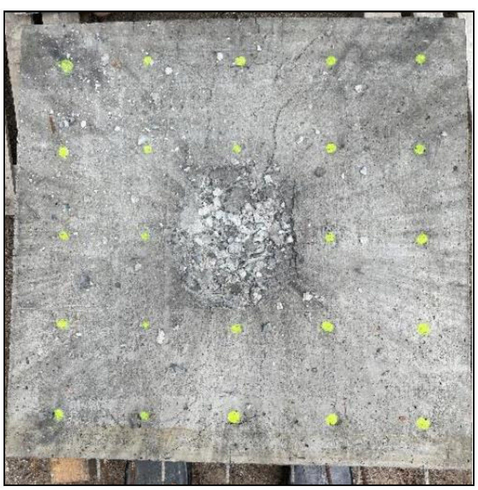

Figure 11. Topside of specimen No. 1.5

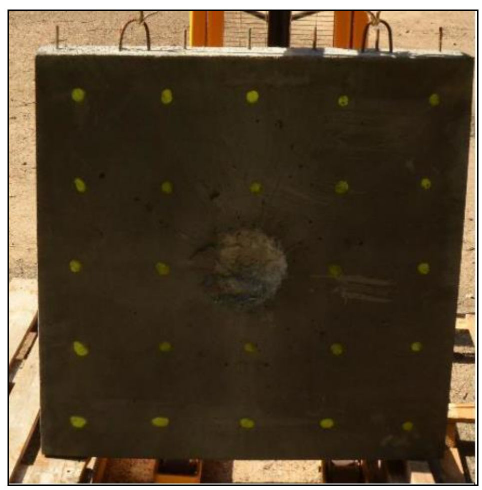

Figure 12. Topside of specimen No. 2.5

4. Conclusion

The experimental program was focused on behaving steel-concrete specimens subjected to blast loading. The emphasis of the experimental program was mainly focused on different ways of assuring the composite action of steel and concrete. For the purpose of the experimental program six types of assuring composite action were chosen. For each type two specimens were prepared – first of them was casted from NSC, the second one from UHPFRC.

Overall, better blast resistance was achieved with UHPFRC specimens than with NSC specimens. Due to the excellent material and mechanical properties of UHPFRC mixture less cracks and other damages occurred on the surface of the specimens. The best results were achieved for the specimens sandwiched in steel plates which help spread the stress. These specimens experienced no visual damage than the top steel plate was puncture into concrete.

The assumption of a positive effect of bonding elements on ensuring composite action was confirmed. Specimens, where shear connectors were used, achieved better integrity of concrete and overall greater resistance.

Results from this part of experimental program will be used in the numerical assessment and following parts of the experimental program.

5. References

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6. Acknowledgements

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