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The fibre orientation influence in cementitious composite against extreme load resistance

R Lovichova[1], J Fornusek[1], M Mara[1], M Kocova[1] and Z Rihova[1]

1 CTU in Prague, Czech Republic, Faculty of Civil Engineering, Experimental Centre
E-mail: romana.lovichova@fsv.cvut.cz

Abstract. This paper is focused on resistance of steel fibre-reinforced cement composite against impact of the deformable projectile shot from the 7.62 × 39 caliber. Different values of resistance against impact of the projectile are caused by different orientation of the fibres. The influence of formwork position, which is the main cause of the different orientation of the fibres, is investigated. The resistance was examined on thirty slabs made of ultra-high performance fibre-reinforced concrete (UHPFRC). Fifteen specimens with vertical orientation of formwork and fifteen with horizontal orientation of formwork was made. The resistance is classified according to the visual evaluation and local damage measurement on the front side and the rear side of the examined specimens. The experiment shown positive influence of vertically oriented formwork on the slabs according to their resistance against impact of the projectile.

1. Introduction

Currently, main protection against shooting from handguns at military and police posts in areas of armed conflicts are used a sandbags and sacks filled with other loose materials. Construction of “sack walls” is overall technically and physically complicated. Furthermore, sacks are mostly made of jute because of its low price. But they degrade relatively quickly under weather conditions and damaged bags spill out filing material which reduce the protection in time. Resistance against extreme loads is increased by the use of ultra-high-grade reinforced steel fibers to reduce brittleness and increase material ductility. The slabs of UHPFRC provide good ballistic protection and their relatively low weight allows their quick assembly and disassembly of protective constructions. Moreover high quality products of UHPFRC enable a long service life even when they are exposed to heavy weather conditions. It is necessary to deal with this topic because positive results could lead to the introduction and putting of these materials into the construction procedures and practice. Especially in structures requiring protection against shooting or explosions.

2. Material Description

This chapter deals with the production of tested samples and description of their mechanical properties. Ultra-high-performance fiber-reinforced concrete containing fine-grained aggregate up to fraction 1 mm was used for our experiments. The composition of the mixture was taken according to the utility model by the originators Kolář et al. [1]. The weight ratio of the individual components of the mixture is shown in Table 1. The amount of steel fiber content was stated as 2 % of the mixture volume. The content of fibers and their orientation affects the mechanical properties of fiber concrete. Therefore, the different positioning of the formwork during the laying of the concrete mixture can be a way of achieving different orientation of the fibers on one flat element.

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Table 1. UHPC mixture expressed in weight ratio [1].

Components of UHPC	
Cement CEM I 42.5R	1.00
Water	0.30
Microsilica	0.10
Silica fume	0.25
Silica sand 0.1 - 1.2	1.60
Plasticizer 1	0.01
Plasticizer 2	0.001

Thirty slabs were made for the planned experimental program on the shooting range. These concrete slabs with reinforced steel fibers had dimensions of 300 × 400 mm and thickness of 50 mm. Fifteen of them were made in a vertical formwork (see Figure 1a) and fifteen in a horizontally stored formwork (see Figure 1b). The samples were de-molded after 24 hours. Also testing samples with dimensions of 40 × 40 × 160 mm were produced with each series of slabs (see Figure 1c) to obtain the average results of mechanical. Prisms were weighed and measured to determine the volume density of each testing mixture. Three-point bend test was carried out after 28 days and then a compressive strength was also tested on the one part of specimen left after the three point bending test - dimensions of contact area 40×40 mm. Amount of samples was set on three for both tests. The average volume density was measured as 2373 kg/m^3. Average results of obtained mechanical properties such as the average of compressive strength (f_c) was 157.1 MPa and the average of flexural strength (f_b) was 26.6 MPa [2].

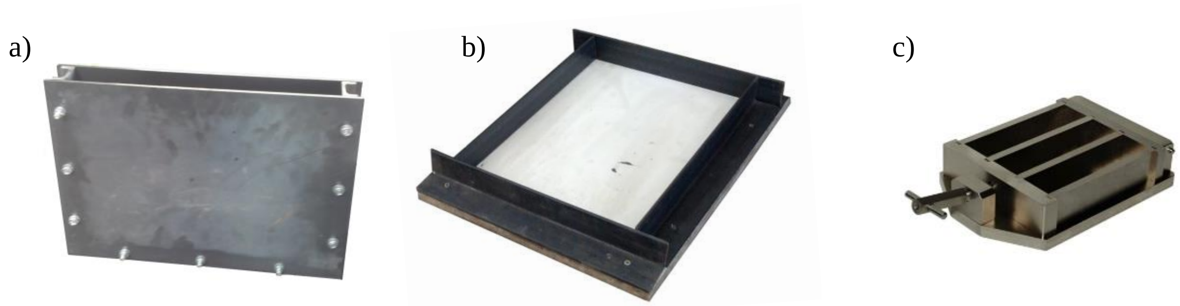

Figure 1. Formworks for slabs and testing samples
a) vertical slabs 300×400×50 mm; b) vertical slabs 300×400×50 mm;
c) testing samples 40×40×160 mm

3. Experimental Program

Experimental program was realized on the shooting range. Testing conditions were adjusted as close as possible according to a standard EN-1522 and EN-1523 [3, 4] and to the shooting range options. Concrete penetration resistance was performed on the thirty slabs made from UHPFRC with dimensions 300 × 400 mm and thickness of 50 mm. The half of the slabs was made in a horizontally placed formwork and the other half in a formwork placed vertically. The aim was to verify if the formwork position in the production of the specimens had an effect on the resistance against an extreme loads, such as projectile hit. Each specimen was placed into the special mount with simulation of point supports by two screws in each corner. Projectile was fired from the distance 20 m to the specimen (Figure 2). Each slab was hit only once and to the center. Then, condition of the slab after the hit was captured by digital camera and analyzed. Proposed types of projectiles were 7.62 × 39 FMJ with lead core in all cases (Figure 3). The appointed projectile has ogive nose, diameter of 7.92 mm, mass of 8.04 g and initial energy 2030 J [5, 6].

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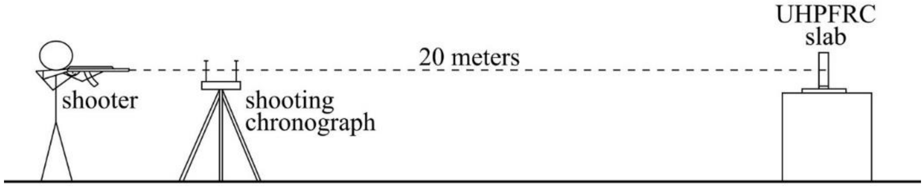

Figure 2. Schema of the applied testing system shooting range.

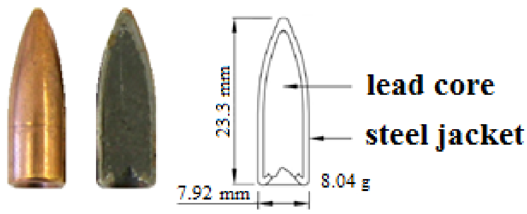

Figure 3. Deformable projectile 7.62 × 39 FMJ with lead core.

4. Results and Discussion

The impact assessment of the projectile is based on the criteria used in the work of Vossoughi et al. [7]. The effects are divided into the following four categories: P - perforated (the projectile passed through the specimen entirely), PL - perforation limit (projectile was stuck), UP - unperforated (specimen was punched but projectile bounced), PB - perforated and then bounced. The observed effects on the individual slabs are in Table 2 - the formwork laid horizontally is described on left and the formwork stored vertically is on the right.

Table 2 Effects of deformable projectile on the slabs made of UHPFRC.

Horizontally stored formwork				Vertically stored formwork			
Impact response of concrete	Excavation of material on the back side	Avg. crater width - front side [mm]	Avg. crater width - back side [mm]	Impact response of concrete	Excavation of material on the back side	Avg. crater width - front side [mm]	Avg. crater width - back side [mm]
UP	NO	45	120	UP	NO	60	105
UP	YES	55	120	UP	YES	60	80
UP	YES	50	80	UP	NO	55	95
UP	NO	75	75	UP	NO	55	80
UP	YES	55	90	UP	NO	60	100
UP	NO	60	100	UP	NO	55	115
UP	YES	65	100	UP	NO	75	80
UP	YES	55	100	UP	NO	60	115
UP	YES	50	125	UP	NO	70	115
UP	YES	55	105	PL	NO	55	100
UP	NO	60	120	UP	NO	55	75
UP	YES	60	125	UP	NO	55	75
P	YES	75	100	UP	NO	55	115
UP	NO	70	100	UP	NO	55	60
PB	YES	55	100	UP	NO	60	75
	Average [mm]	59	104		Average [mm]	59	92

The left part of the Tab. 2 shows that a complete shoot through the slab occurred in only one case (Fig. 4) and in another only case a hole was formed, with the projectile bouncing off. Since both of these cases are from one series, it can be assumed as an error during the production which subsequently manifested this behaviour. In other cases, the projectile was deflected but it created a crater at the front (Fig. 5) and back side of the slab. There was a scabbing on the back of the slab in some cases and the material was broken out by the tensile stress (Fig. 6), it was occurred in 66 % cases. In the remaining cases, there was also a breakdown due to tensile stress, but the structure and the greater tensile strength of the material allowed only a material deformation and cavity formation within the investigated slab (Fig. 7). The average width of crater on the front and back side was 59 and 104 mm.

Fig. 4 UHPFRC slab with hole passing through overall thickness

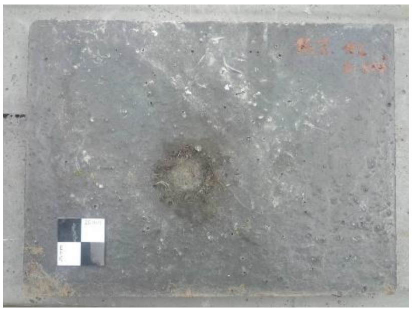

Fig. 5 Crater after projectil impact on the front side of the slab

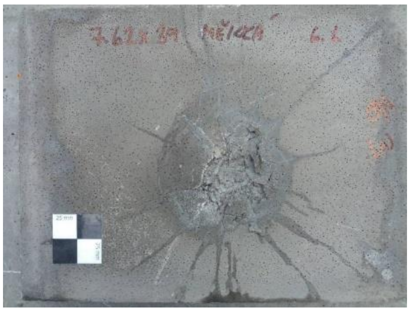

Fig. 6 Tearing of material from the back side of the board due to tensile stress

Fig. 7 The back of the board where the material has been stuck

Between samples made in a vertically stored formwork (right side of Table 2), there was only one slab where the projectile stayed stuck inside the slab (Fig. 8). In other cases, a projectile created a crater and then bounced off after impact (Fig. 9). There were also signs of tensile stress on the back side which was caused by the spread of the pressure wave after the impact of the projectile. It can be seen from the table 2 that material tear-out on the back side of these slabs has occurred only in one case out of the fifteen samples, i.e. for 93 % of the vertical slabs, the material still held together in one piece (Fig. 10). The created craters on the front and the back of the slabs formed in the horizontal formwork had an average width of 59 mm and 92 mm.

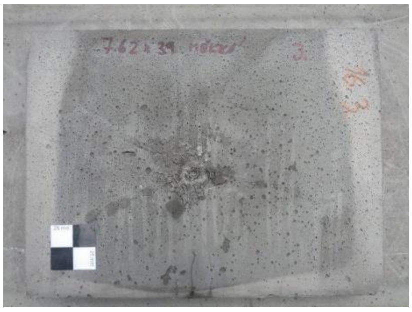

Fig. 8 Projectile stuck in the UHPFRC

Fig. 9 Crater on the front side after impact

Fig. 10 The back side of the slab where the material has not been riped out

5. Conclusions

The test evaluations obtained the following results. There was two-thirds of horizontal UHPFRC slabs where the material was torn-out from the rear side and only one case out of fifteen vertically poured UHPFRC slabs. The average crater width at the front side of the UHPFRC slabs is the same for both types of formwork orientation. Its value is 59 mm. The average width of the crater at the back side of the vertically oriented UHPFRC slabs is by 12 mm smaller. The results show a considerable positive effect of the formwork orientation on the extreme load resistance, which is achieved in this work by the projectile impact of the 7.62 × 39 caliber rifle. The formwork orientation has almost no effect on the endurance of the front side of the UHPFRC board. The stress strengths of the load tests ranged from 130 MPa to 199 MPa and a flexural tensile strength of 15 MPa to 41 MPa. However, it is clear from the results of the UHPFRC projectile impact resistance testing that the strengths within these ranges do not have a visible effect.

The separation of material on the rare side is decisive - slabs with a vertical formwork does not occur rapture of the material on the back side. This is due to a better transfer of tensile stress induced by the pressure wave after the impact of the projectile. Based on this work, it is recommended to use slabs made of ultra-high performance concrete reinforced with steel fibers, oriented vertically.

6. References

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