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The Thickness Influence of Fibre-reinforced Slabs on Extreme Load Resistance

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Abstract. This paper deals with slabs made of ultra-high-performance fibre-reinforced concrete (UHPFRC) and experimentally verifies the influence of their thickness on projectile impact resistance for different calibers and the different resulting impact energies. It describes the classification of different thickness of UHPFRC slabs according to available European standards and military standards into the respective degrees of ballistic protection. The effectiveness of ballistic protection of tested slabs are checked according to standardized testing procedures for a personal ballistic protection. The aim is to determine the necessary thickness of the slabs to stop bullets of a certain impact energy. Therefore, optimize the amount of material used with regard to the required ballistic protection.

Introduction

Sandbags and sacks filled with other loose materials are in these days used as a main protection against shooting from handguns at military and police posts in areas of armed conflicts. Construction of sack walls, in many cases created in combination with trenches, is overall technically and physically complicated task which is often carried out in dangerous areas with a threat of shooting. Moreover, 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 protection. Therefore, the aim is to speed up and simplify the construction process of ballistic protection systems.

The slabs of UHPFRC provide good ballistic protection and their relatively low weight allows their quick assembly and disassembly of protective constructions. Thereby the time, when people are in danger during a building up protection, is reduced. Moreover high quality products of UHPFRC enable a long service life even when they are exposed to heavy weather conditions.

Material Description

Ultra-high-performance fiber-reinforced concrete containing fine-grained aggregate up to fraction 1 mm was used for our experiments. The UHPFRC with 1.5 % steel fiber content in mixture volume was chosen. The devised mix for UHPC (containing mixture of cement, microsilica, aggregate and plasticiser) was specially prepared and delivered in 12 kg bags.

The volume of fibers and water were weighed to suit the required resulting strength of the mixture and were added into the mixture during the mixing process.

The mixture was poured into the horizontal formwork with dimensions 300×400 mm and variable thickness *t* of 1, 2, 3, 4 and 5 cm. The samples were de-molded after 24 hours. The impenetrability of UHPFRC slabs was experimentally tested for respective slab thicknesses *t*.

Average results of obtained mechanical properties (such as flexural strength f_b and compressive strength f_c) in 7 and 28 days after casting of mixture are shown in Table 1. The flexural strength was tested by three point bending test on prisms 40×40×160 mm. The compressive strength was tested on the one part of specimen left after the three point bending test, in a press with dimensions of contact area 40×40 mm. Amount of samples was set on twelve for both tests.

Table 1. Flexural and compressive strength of used mixture.

	f_b [MPa]	f_c [MPa]
7 days	13.8	108.3
28 days	14.2	122.0

Experimental Program

Samples with a minimum age of 28 days were tested on the shooting range. Testing conditions were adjusted as close as possible according to a standard EN-1522 and to the shooting range options [1]. Each specimen was placed into the special mount with simulation of point supports by two screws in each corner. With regard to the safety of the shooter, some non-standardized distances of the shooter and target were also selected [2]. Projectiles were fired from the distance 6 meters to center of specimen for handguns (“short firearms”) and 20 meters for rifles (“long firearms”). A shooting system is schematically shown below, see Fig. 1. The slabs were oriented such that the bullets hit the slabs in direction perpendicular to its own plane, thus against the smallest mass of material which should be the worst possible scenario.

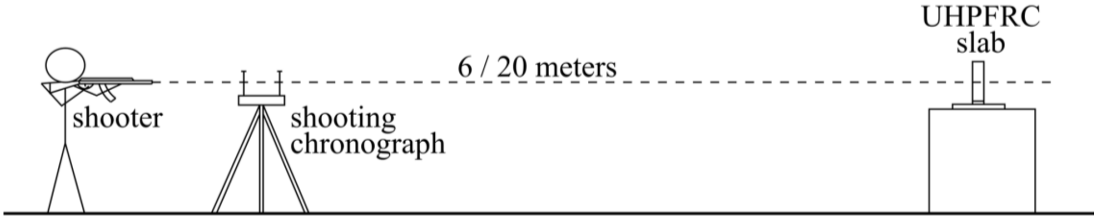

Fig. 1 Schema of the applied shooting system.

Results

Low-thickness slabs have not been optimally created because fibres formed clumps in mixture that could change the thickness of the slabs in the range of ± 5 mm. For slabs with higher thickness, this problem did not occur that much and maximal variance of thickness was within ± 2 mm on the edges. Therefore, thin slabs (mainly 1 cm) are difficult to make in appropriate quality. For that reasons, slabs with thickness 1 cm fulfilled the supplementary assumption as the slabs failed to stop bullets of the smallest .22 caliber (5.6x15 mm).

Fig. 2 1-cm slab – .22 caliber on the left, 9 mm Luger caliber on the right side of the slab.

Fig. 3 1-cm slab – back side – crater after 9 mm Luger on the left and crater after .22 caliber on the right side oft he slab.

Another series of slabs with 2 cm in thickness easily stops the bullets of .22 caliber but 9 mm Luger caliber still penetrate the slabs through. The 9 mm Luger caliber from short or long firearms and even the 7.62x25mm Tokarev caliber are unable to penetrate the 3 cm thick slabs. These slabs stops first bullet of the .44 caliber but cannot withstand other following bullets of this caliber.

Fig. 4 2-cm slab – three small craters are from .22 caliber, one bullet hole in the middle is from 9 mm Luger caliber.

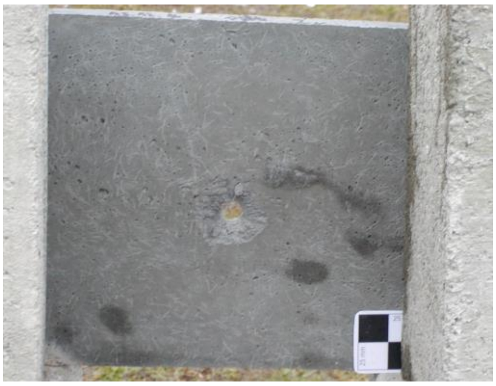

Fig. 5 2-cm slab – back side – nothing visible from .22 caliber and bullet hole from 9 mm Luger caliber.

Fig. 6 3-cm slab – hit from 9 mm Luger caliber on the left and two hits from 62×25 mm Tokarev caliber on the right side.

Fig. 7 3-cm slab – three hits from .44 Magnum caliber.

Slabs of 4 cm thickness stop with certainty bullets of .44 caliber, however all other bigger caliber (rifles) with much higher impact energy were able to penetrate the whole thickness of the slab. The last group of 5 cm thick slabs was tested on 7.62x39 mm caliber with soft or steel core and .223 Remington civil caliber. Bullets from 7.62x39 mm soft core and .223 calibers were stopped by the slab, but the back side of the slab was heavily damaged. The 7.62x39 steel core caliber was able to penetrate the slabs though.

Some samples of the hit slabs of all the tested thicknesses are shown on Fig. 2 – Fig. 11.

Fig. 8 4-cm slab – craters after .7,62x39 mm soft core caliber (two upper did not go through, lower did).

Fig. 9 4-cm slab – back side – craters after .7,62x39 mm soft core caliber (two upper did not go through, lower did).

Fig. 10 5-cm slab – craters after .7,62x39 mm steel core caliber (two upper did not go through, lower did).

Fig. 11 5-cm slab – back side – craters after .7,62x39 mm steel core caliber (two upper did not go through, lower did).

Conclusions

Overall, the experiment can be considered as successful. The slabs made of UHPFRC provide good ballistic protection and their relatively low weight allows quick assembly and disassembly. Thereby, the people who build up the protection are exposed to risk for reduced time. It may be assumed that a police application does not need protection against military calibers, but there is more needed fast assembly and disassembly of any inhibitions. Therefore, slabs with lower thickness (3 – 5 cm) but sufficient protection against short guns can be used. While military applications can utilize the full potential of ballistic protection of thick (5 cm and more) UHPFRC slabs. Furthermore, high quality of the UHPFRC products allows a long service life even if they are exposed to strong weather conditions which allows various positions on the market for differently thick slabs according to various levels of ballistic protection.

Most of the slabs can be classified according to EN-1522 to the appropriate category of ballistic protection but even though the standard EN-1522 is widely recognized as sufficient, it is focused more on the handguns than on rifles, for which the difference in impact energy is multiple. Nevertheless, for civil usage is the standard EN-1522 sufficient and slabs with thickness of at least 5 cm can withstand most of the civil used guns [3].

Acknowledgement

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