Lightweight Protective Sandwich Structure with UHPC Core

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Abstract

Ultra-high performance fiber-reinforced concrete (UHPFRC) can be used to build lightweight bulletproof structures because even its thin layer can prevent projectile perforation. UHPFRC is significantly less expensive than other armor materials such as steel, Kevlar, nylon, or ceramic. It has good volume stability and very low porosity, which makes it highly durable and provides sufficient resistance to freeze-thaw cycles. However, when a projectile hits a thin UHPFRC structure, the fragments can break off. The fragments can injure people or damage property in the vicinity of the structure. To address this problem, we have developed a new generation of sandwich structures consisting of a UHPFRC core, a fiber-reinforced epoxy composite, and an elastomeric coating. UHPFRC and composite provide penetration resistance. Composite and elastomer reduce fragmentation of UHPFRC. By properly designing these three materials, their thickness, and their position in the sandwich structure, lightweight and affordable bulletproof panels can be produced. This contribution presents such a structure and subjects it to ballistic testing according to European and American standards. It is shown that the additional layers eliminate the formation of rear fragments after projectile impact and reduce the panel weight by 13% compared to the panel made entirely of UHPFRC. Due to their unique shape, the panels can be combined to form a mobile and modular protective barrier. The barrier can take the form of a freestanding wall with various opening angles, or an outpost with a square or hexagonal base. It can be moved and assembled quickly by just two people.

Keywords: Ballistic resistance, thin-wall, sandwich, UHPFRC, glass/epoxy, polyurethane coating

1. Introduction

A new ballistic system has been invented for e.g. special checkpoints, unique fortified posts, mobile city barriers, or other similar structures (Fornůsek et al.), see Figure 1. The system consists of lightweight, easily manipulated UHPFRC panels. The panels are equipped with locks that allow the panels to be joined together and create a ballistic structure. The locks allow the adjacent panels to be rotated within the defined angle. The system can thus take the form of a free-standing wall with different opening angles or an outpost with a square or a hexagonal base. Two people are enough for the construction, which is very fast and does not require technological breaks or heavy machinery.

Mára et al. subjected the panels or the entire system to bending, shearing, punching, blasting, or ballistic tests. They concluded that the panels had adequate blast and ballistic resistance. They suggested that UHPFRC fragmentation could be completely eliminated by adding internal non-metallic reinforcement or additional layers on both sides of the panel. This contribution proposes a new panel design with a sandwich structure of a UHPFRC core, additional glass/epoxy layers, and polyurethane coatings.

Figure 1: The mobile ballistic barrier consisting of bulletproof panels of UHPFRC (MOB-Bars s.r.o.).

2. Materials and Methods

The proposed sandwich structure consists of a 30 mm UHPFRC core with a density of 2384 kg/m^3 (1.378 oz/in^3) and 1.5% volume of fibers, additional 3 mm glass (INTERGLAS™ twill 2/2) / epoxy (CHS-EPOXY® 582 + TELALIT® 0542) layers of 1770 kg/m^3 (1.023 oz/in^3), and 5 mm thick polyurethane coatings of 1182 kg/m^3 (0.683 oz/in^3) with a 30% weight of filler.

The sandwich structure was ballistic tested according to the European (EN 1522:1998) and US (NIJ Standard-0101.06) standards. In addition, the thickness of the panel made entirely of UHPFRC, which meets the requirements of each ballistic class, is also determined for comparison.

3. Results

Table 1 shows the minimum thickness of the UHPFRC panel that meets the requirements of different ballistic protection classes. The sandwich structure meets ballistic class requirements up to FB4 and IIIA with no rear secondary fragments separated. Figure 2 shows the post-test photos of the sandwich structure.

Table 1: Classification of UHPFRC panels of different thicknesses according to E.U. and U.S. standards

Standard	2 cm (0.79 in)	3 cm (1.18 in)	4 cm (1.57 in)	5 cm (1.97 in)	7 cm (2.76 in)	8 cm (3.15 in)
EN-1522	FB2	FB3	FB4	FB5	FB6	FB7
NIJ-0101.06	I	II	IIIA	III	III	IV

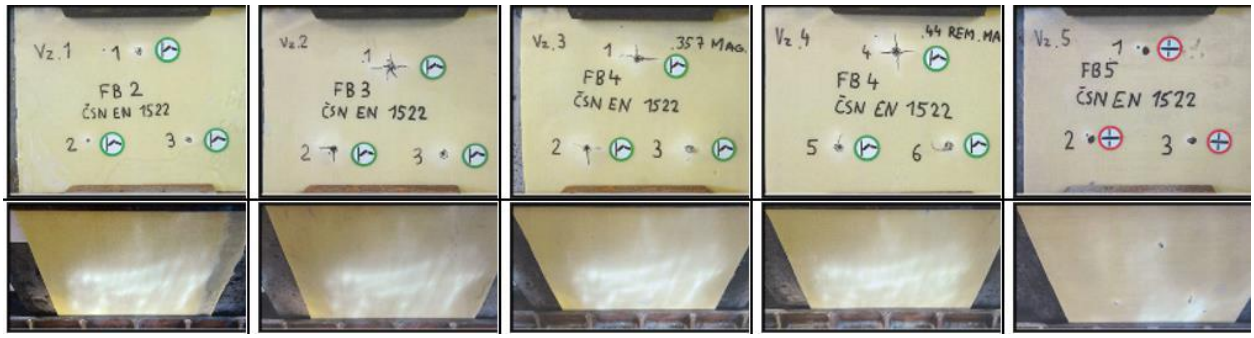

Figure 2: The front (top) and back (bottom) faces of sandwich structures tested to EN 1522:1998.

4. Discussion and Conclusions

By adding layers of glass/epoxy and polyurethane, the thickness of the UHPFRC core was reduced and the overall weight was reduced by 13%. In addition, the formation of rear fragments after projectile impact was completely eliminated. A follow-up study will further optimize the sandwich composition and present sandwich panel designs that meet the requirements of higher ballistic protection classes.

5. Acknowledgements

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6. References

- Ballistic Resistance of Body Armor, NIJ Standard-0101.06, U.S. Department of Justice, Office of Justice Programs, National Institute of Justice, Washington, DC, 2008.

- Fornůsek, J., Jelínek V., Mára, M., Sovják, R. and Zatloukal J., Ballistic Panel and Ballistic System. US Patent US 10,648,780 B2, United States Patent and Trademark Office, 12 May 2020.

- Mára, M., Talone C., Sovják, R., Fornůsek, J., Zatloukal, J., Kheml, P. and Konvalinka, P.. "Experimental Investigation of Thin-Walled UHPFRCC Modular Barrier for Blast and Ballistic Protection." *Applied Sciences*, vol. 10, no. 23, 5 Dec. 2020, p. 8716.

- MOB-Bars s.r.o, "MOB-Bars, protective barrier systems | Universal and flexible mobile ballistic barriers or mobile and stable elements for decelerating and stopping the vehicle", Effective Date, December 3, 2016, Available at https://www.mob-bars.com/ [Cited February 21, 2023].

- Windows, doors, shutters and blinds - Bullet resistance - Requirements and classification, EN 1522, European Committee for Standardization, Brussels, Belgium, 1999.