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Penetration resistance of semi-infinite UHPFRC targets with various fiber volume fractions against projectile impact

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Abstract

Penetration resistance of Ultra-High-Performance Fiber-Reinforced Concrete (UHPFRC) was investigated within the framework of this study. Fiber volume fraction was set as the main test variable and two types of projectiles have been used. Deformable and non-deformable projectile had a full metal jacket with soft lead core and full metal jacket with mild steel core, respectively. Both projectiles were 7.92 mm in diameter and weighed 8.04 grams. Semi-infinite targets made of UHPFRC have been constructed with five different fiber volume fractions with gradual increments ranging from 0.125% to 2%. For the means of comparison, additional plain mixture specimens were casted. Semi-infinite targets have been introduced by using UHPFRC cubes of 200 mm in size. Projectile impact was simulated by using semi-automatic rifle calibre 7.62 × 39 mm at the shooting distance of 20 m. Muzzle velocities for both type of projectiles were around 710 m/s and only front crater with the tunnelling section occurred at the proximal face of the specimen. Depth of penetration, crater diameter and crater volume have been investigated based on various fiber volume fractions and various projectiles. The results from UHPFRC targets were compared with theirs plain mixture counterparts and among different fiber volume fractions. It has been experimentally verified that using steel fibers in the ultra-high performance concrete matrix results in lower damage in terms of depth of penetration, crater area and crater volume, while the latter two are far more affected by the increase of the fiber volume content than the former. Using short steel fibres as disperse micro-reinforcement provides enhanced performance of semi-infinite UHPFRC targets and is therefore essential for construction of protective structures in order to reduce the damage of the impacted elements and to increase the safety of the personnel.

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Keywords: UHPFRC; semi-infinite; fiber-reinforced; projectile; deformable; non-deformable; depth of penetration; impact crater; area; volume.

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1. Introduction

In the recent years, a lot of focus in the field of impact resistance of advanced construction materials can be observed. One of the materials that demonstrated improved ability to resist high velocity projectile impacts was Ultra-High-Performance Fiber-Reinforced Concrete (UHPFRC), which is a composite of well-established high-performance concrete matrix and high-strength steel fibers. This material has greater standard mechanical properties than ordinary concretes, as well as improved strain-hardening behaviour, reduced brittle failure and much greater capacity to absorb the force impulses by dissipating the impact energy through ductile deformations.

This paper presents the procedure and results of an experimental study on the impact resistance of UHPFRC semi-infinite targets subjected to high velocity projectile impact (HVPI) by deformable and non-deformable projectiles. The plain ultra-high-performance concrete mixture, which remained constant through this research, was already optimally designed by previous work done by Bažantová and Kolář in 2015 [1]. The only variable in the UHPFRC mixture was the fiber volumetric fraction, which was set as five different volumetric percentages varying according to the logarithmic scale with the base of 2 and achieving the maximum fiber volumetric content of 2%. The semi-infiniteness of the targets was achieved by using samples with a shape of 200 mm side cubes, which assured, that the penetration depth, predicted as less than 50 mm, is not affected by the target thickness. The other controlled variable in the study was the deformability of the projectiles – cores of the deformable projectiles were made of a soft-lead alloy, whereas the non-deformable projectiles had a mild-steel core with a smaller lead tip. The projectiles were fired at the average muzzle velocity of 710 m/s from 20 m distance from the target. Evaluation of the damage of HVPI on targets included laser scanning of crater profiles in horizontal and vertical directions, measuring the maximal depth of penetration (DOP), measuring distances between boundary points of the inner craters in horizontal and vertical directions, and calculating and measuring the area and volume of the craters.

The main motivation factor behind the study was to determine the quantifiable influence of small increments of the fiber volumetric content to impact resistance in the terms of measurable damage degrees and to determine the difference in the impact resistance of plain high-performance concrete specimens and theirs variously fiber reinforced counterparts.

In the recent past, a numerous experimental investigations were performed in order to determine the actual influence of incorporation of steel fibers into the plain concrete matrix on the significant damage degrees, such as depth of penetration, area and volume of the crater, produced by HVPI. However, they were in the majority conducted using non-deformable projectiles impacting semi-infinite, finite or confined concrete targets. All of the researches confirmed the supposition that compared to plain concretes or conventional reinforced concretes, the fiber reinforced concretes can provide better impact resistance. This was attributed mainly to the increased toughness and hardness of material [2]. However, after the certain percentage of fiber volumetric content, the DOP was not decreasing significantly anymore. On the other side, the higher contents of fibers did provide better resistance in the terms of reduced crater area and volume, but were fairly insignificant to the DOP [3–5]. This behaviour was explained by the fact, that addition of steel fibers increases the compressive strength of the concrete, which consequently reduces the penetration depth, whereas the direct effect of fibers lays in the bridging effect of arresting the crack propagation, which results in reduced area and volume of the craters [6]. Other research [7] concluded, that while the higher compressive strengths in plain concrete lead to more brittle behaviour and larger crater dimensions, the influential degree of incorporation of fibers on reducing the crater dimensions is much higher. It was therefore established that the DOP is in the correlation with the compressive strength and consequently also with the fiber volumetric content, since the increase of the latter results in higher compressive strengths. The decrease of the area and volume of the impact crater can be assigned only to the increase of fiber content, since the addition of fibers improves the fracture toughness and dynamic tensile strength of the material [8].

A similar investigation was already conducted by Máca et al. [9], although it was performed on 50 mm thick slabs, simulating targets with finite geometries, which have different behaviour as theirs semi-infinite counterparts. The same steel fibers as in this research were added in three different volumetric contents (1%, 2% and 3%) and the impact was simulated with the same projectiles as in this research. The results showed that incorporation of the fibers can improve impact resistance in form of decreasing the DOP and crater diameter. However, in the case of non-deformable projectiles increasing the content of fibers beyond 1% or 2% did not further influence the DOP or crater diameter, respectively. Therefore the optimal amount of fibers was established to be at 2% of volume, which