RESISTANCEOFULTRA HIGH-PERFORMANCE CONCRETEWITH BASALT ADDITION AGAINST PROJECTILE IMPACT

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Abstract - The aim of this paper is focused on the influence of the basalt as a coarse aggregate in ultra high-performance concrete (UHPC) on its resistance against extreme load. The paper deals with a projectile impact resistance of ultra high-performance steel-fibre-reinforced concrete (UHPFRC) in terms of depth of penetration and size of the crater. The samples made of UHPFRC with different types and quantities of basalt were designed and produced, to be subjected to impact loading in the form of projectile impact. Damaged surface of samples were scanned by means of a 3D scanner and the damagedparts was evaluated. The main goal of the paper was to find the optimum content of basalt as a coarse aggregate in the mixturein order to improve its resistance againstprojectile impact.

Keywords - Ultra High-performance concrete,UHPC,UHPFRC, coarse aggregate,basalt, projectile impact, depth of penetration, crater surface, 3D scanning.

I. INTRODUCTION

Recently, great emphasis is placed on durability, strength and safety of concrete structures, particularly civil and military structures, which could be the target of intentional or accidental impact loads.Especially these structures, including objects of strategic importance(such as government buildings, reinforcements, defence shelters or other protective structures), must be resistantagainst this type ofdanger. The elements and their material are designed to withstand the possible extreme loads that can be caused by projectiles, fragments, explosions, cars or aircraft impact, earthquakesor terrorist attacks. The ultra high-performance concrete (UHPC) with a dispersed steel reinforcement (UHPFRC) is one of the high potential materials to use in these cases. This research is focused on improving the resistance of UHPFRC slabs to projectile impact, with aiming to improve the properties while maintaining the thickness and weight of the slabs for easy handling.The workability of fresh concrete become worse when the amount of steel fibres is increased above a certain boundary, there is also a reduction in compressive strength and modulus of elasticity, as is already known from previous studies [1,2,3]. Therefore, this work focuses on the improvement of UHPFRC by the addition of coarse aggregate in the form of basalt.

The resistance of cement composites against projectile impact depends on many aspects. Impact resistance improvement in terms of penetration depth and crater diameter can be achieved by reducing the water-to-cement ratio and by increasing compressive strength of the concrete.The presence of dispersed steel fibres reduces the diameter of the crater.Therefore, the use of UHPFRC is the ideal solution for constructions that could be potentially exposed to impact loads.The traditional fibre-reinforced concrete (FRC) with ordinary strength matrix has a high energy absorption capacity when projectile hit. However, studies show that UHPFRC has a much greater energy absorption capacity in both quasi-static and dynamic loading [4].The resistance of the concrete against the impact of the projectile is also affected by the size, strength and hardness of the added aggregate. In order to achieve a higher compressive strength, the presence of coarse aggregate in UHPFRC is usually reduced or even eliminated to achieve the required homogeneity and density of the mixture.Thus, the anti-penetration capabilities of coarse aggregate have been almost neglected. Nevertheless, later, in the projection penetration experiments conducted by Zhang et al. [5], Langberg andMarkeset [6] or Wu et al. [7], it was found that the penetration depth of the projectile does not decrease further when the compressive strength of the concrete reaches a certain boundary.The optimal compressive strength of UHPFRC for the protective structure construction has been designed to be 90-150 MPa, taking into account the comprehensive considerations of protection efficiency and cost of production [4].

II. MATERIAL AND MIXTURES

Basalt is a fine-grained extrusive rock (Figure 1). It was chosen as a coarse material for UHPFRC, mainly because of its very high hardness (Mohs hardness scale number 7) and its wear-out resistance. An experimental study with UHPFRC with added basalt as coarse aggregate (UHP-BASFRC) was carried out by Wu [4], whofocused on UHP-BASFRC samples with different contents and different corundum fractions. The samples were tested by a projectile with impact velocity in the range of 510-850 m/s, an average mass of 341.2 g and a diameter of 25.3 mm. From the results, it was concluded that when the aggregate grain size increases, the concrete achieves

higher compressive strengths. When the fraction was changed from 5-20 mm to 35-45 mm, the compressive strength increased by 18%.

In terms of depth of penetration (DOP) of the projectile, it can be stated that when the aggregate grain size is increased from 0.5d (where d is the diameter of the projectile) to 1.5d and 2.5d its value decreases gradually. With increasing grain size of filler,the probability of a direct hit of coarse aggregate particles increases. Therefore, it is possible in this way greatly enhance impact resistance ofUHPFRC, if coarse aggregate with high hardness and strength is used.

After the impact of the projectile, the surface of the crater decreases as the grain size of the added coarse aggregate increases. Slightly better results are also obtained whenthe content ofbasalt in the mixture is increased [4].



Fig. 1 Basalt, fraction 0-2 mm



Fig. 2Basalt, fraction 4-8 mm

Within the experimental program, three types of mixtures were proposed - one reference mixture and two other mixtures with a variable percentage of basalt (20% and 30%). All slabs were made in a thickness of 50 mm and a size of 400×300 mm. The steel fibres were 13 mm in length and 0.15 mm in diameter.The amount of added fibres for all samples was 1.5% by volume of the resulting composite.

A dry prefabricated mixture of a multifunctional silicate composite [8] was used, to which the basalt was added. This prefabricated mixture comprises a cement matrix which forms a ground cement clinker with a specific surface area of more than 150 m^2/kg.The dry prefabricated mixture contains thehigh-range water reducer, a defoaming agent, silica-fume, silica powder and fine sands with a maximal grain size of 1.2 mm. The number of individual components can be seen in Table 1. The water-to-cement ratio of this mixture was 0.3.All specimens were made with 20% and 30% content of basalt from the total volume of the composite. The basalt was used in a 0-2 mm and 4-8 mmfraction; its bulk density was 3200 kg/m^3.

Table 1 Composition of high-performance concrete with basalt

Composition	UHPFRC	Basalt 20 %	Basalt 30 %
Cement	1	1	1
Additives	0.40	0.40	0.40
Water	0.30	0.33	0.35
HRWR	0.025	0.020	0.020
Fine sands	1.76	1.16	1.00
Basalt 0-2 mm	0	0.10	0.20
Basalt 4-8 mm	0	0.18	0.24

For further basalt samples, a custom mixture was designed to meet optimized UHPFRC granulometry. As well as prefabricated mixture contained silica powder, microsilica, a superplasticizer and a defoaming agent. The composition of this mixture can be seen in Table 1. In this recipe, basalt replaced fine aggregates in 20 % and 30 % of the total aggregates content. The mixture uses a cement class 52.5, the water-to-cement ratio was designed to 0.3.

Experimental programme

Besides the slabs, three beams of 160×40×40 mm from each mixture were made. For these samples was performed a three-point test for flexural strength.Average strengths and bulk densities of materials are shown in Table 2. The table is supplemented with the average values of UHPFRC samples made from a dry prefabricated mixture of multifunctional silicate composite without added coarse aggregate.

Table 2 Mechanical properties of ultra high-performance concrete and UHPC with basalt

Mixture	Basalt [kg/m^3]	Compressive strength [MPa]	Tensile strength [MPa]	Density [kg/m^3]
UHPFRC	0	158.0	25.60	2373
Basalt 20 %	212.1	200.0	27.27	2416
Basalt 30 %	340.2	204.0	31.14	2482

An interesting comparison is given in Table 2, where a significant increase in the compressive strength can be observed for samples made of simple UHPFRC (0 % of basalt replacement) compared to samples containing 20 % of basalt - from 158.0 MPa to 200.0 MPa.The increase of pressure strength in samples containing 30 % of basalt compared to samples containing 20 % of basalt is minimal within the limits of standard deviation.

The increasing trend of tensile bending strength is visible depending on the increasing content of basalt (graph on the Fig. 3). For the reference mixture containing 0 % of basalt, the tensile bending strength was measured as 25.60 MPa.The highest value was measured in samples containing basalt of 30 % in the total aggregates content - 31.14 MPa, which was by more than 12 % higher than in samples containing 20 % of basalt and by almost 18 % more than in the reference mix without basalt.

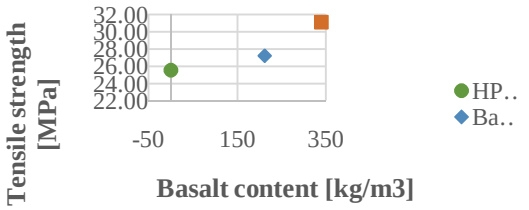


Fig. 3Dependence of tensile strength on basalt content

Prepared slabs of 400×300×50 mm were installed into the holder andsubjected to a projectile impact (7.62×39caliber) on the shooting range. A 7.62 mm full-metal jacket with a soft lead core was used. The weight of this projectile is8.04 g, the velocity of the projectile is around 710 m/s.In the previous experiments it was found that50 mm thick UHPFRC slabs without added coarse aggregate stopped this type of projectile, so it is assumed that the plates with coarse aggregate should also resist this type the projectile [9].

Evaluation of the results was carried out by using the 3D scanner David, which employs two-picture photogrammetry (stereophotogrammetry). For each sample, the crater on the front side was captured using this 3D scanner.

The scanner was placed at a suitable distance and the correct resolution was set and the surface image of the board was scanned (Fig. 4). Pictures from four different angles were taken to capture the entire surface of the crater. These pictures were composed together by software DAVID to created one final 3D picture of the crater.

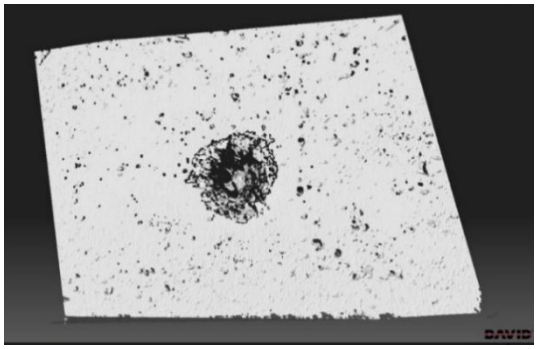


Fig. 4 Picture the 2D surface of the board

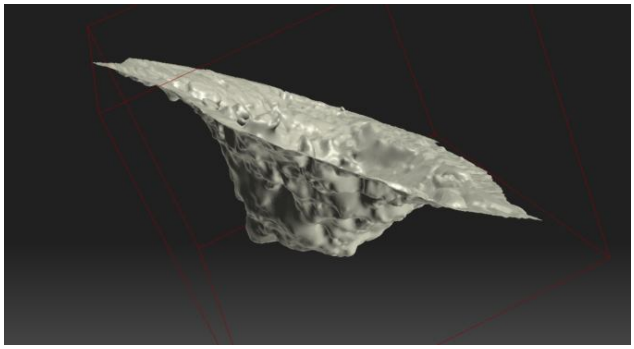


Fig. 5Picture of the 3D crater surface in David 3D

The resulting surface was exported in .obj format (Fig. 5) and subsequently processed in Autocad Civil 3D software. In this program, a point cloud was created from the files which contained the 3D coordinates of the scanned craters.Thereafter, the software created a 3D surface which is able to measure.Also the diameter of the created crater and the penetration depth of the projectile (DOP) were able to be measured by Autocad Civil 3D program.

III. RESULTS AND DISCUSSION

The resulting values of diameter and depth of penetration of the surface craters were obtained using AutoCAD Civil 3D and they are shown in Table 3.

Table 3 Crater dimensions of UHPFRC after projectile impact

Samples	DOP [mm]	Diameter [mm]	2D surface [mm^2]	3D surface [mm^2]
UHPFRC	22.5	67.5	3591	30554
Basalt 20 %	18.6	70.9	4060	26242
Basalt 30 %	22.6	75.5	4482	22714

Table 3 shows some inconsistency in the DOP when increasing the compressive strength of the composite or more precisely, when increasing the contents of the basalt. Samples with 30% basalt content show a higher penetration depth at very high strength, probably due to the low proportion of fine aggregate in the mixture. This may result in poor cohesiveness of large grain aggregates and the rest of the matrix.If the mixture does not contain sufficient fine grain aggregate (the grain curve is filled with insufficient fine grain aggregate), it will occur to microcracks of the composite due to insufficient compaction and compactness of the mixture. Therefore, the depth of penetration in samples with higher basalt amounts was higher.

The chart inFig. 6 showsthe dependence of the depth of penetration on the amount of basalt added. In general,it can be stated, that with the increasing amount of aggregate, the depth of penetration decreases, but the optimal composition of the mixture must be still found. If the grain curve is not filled with sufficient fine grain aggregate, it will occur in the composite to microcracks due to insufficient compaction and compactness of the mixture.

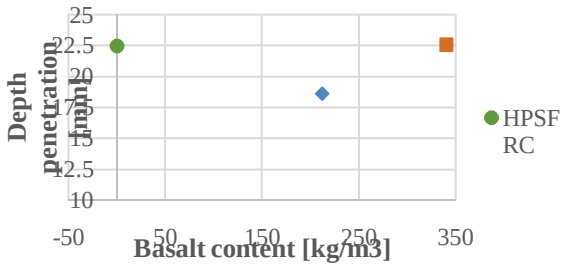


Fig. 6Dependence of depth penetration on basalt content

The next chart (Figure 7) shows the dependence of the diameter of the crater on the amount of basalt added. With the higher content of basalt aggregate in UHPFRC, the diameter of the crater created by the impact of a projectile is increasing.When the basalt content increase from 20 % to 30 %, the crater diameterincrease from 70.9 mm to 75.5 mm. Ifwe compare the mixture with 20 %basalt and reference mixture with 0 % of basalt, the crater diameter drops from 70.9 mm to 67.5 mm.

The 3D surface is a magnitude that tells us the total surface of the created crater. It was detected using a 3D model in Autocad Civil 3D.The model also includes all the irregularities of the sample, which are greatly influenced by the granulometry of the mixture. Hence, the considerable effect on the resulting surface has the size of the grains as well as the content of the individual fractions.The following graph (Fig. 8) shows the reducing the 3D surface of the created craters depending on the increasing the proportion of coarse aggregate.

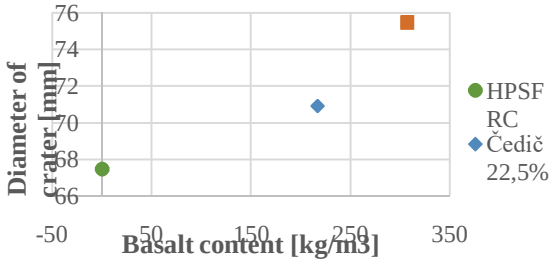


Fig. 7 Dependence of crater diameter on basalt content

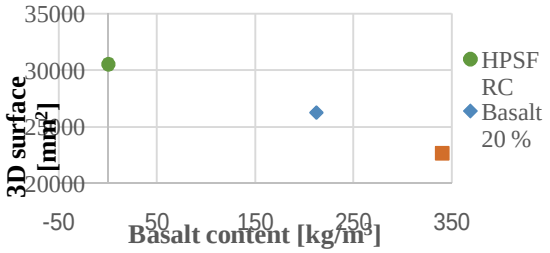


Fig. 8 Dependence of 3D surface on basalt content

The average 3D surface area for the reference mixture was measured as 30554 mm^2, which is more than 14 % higher value than for samples containing 20 % basalt and more than 25 % larger 3D surface than was measured for samples with 30 % basalt content. The increase in the average value of the 3D surface between 30 % and 20 % of the basalt content was 3528 mm2. This finding represents a percentage increase of almost 15 %, with the basalt content being 128.1 kg/m3, i.e. a percentage difference 37.6 %.

CONCLUSIONS

Overall, the experiment can be considered as successful. In terms of resistance to impact of the projectile, it has been found the basalt as an addition of coarse aggregate to ultra high-performance steel-fibre-reinforced concrete (UHPFRC) has a positive effect on its resistance. The depth of sample penetration, as well as the diameter of the crater,

depends on the compressive strength of the composite and on the amount of aggregate added. The higher the compressive strength of the material and the coarser aggregate added to the UHPFRC, the better the impedance properties the material proves. These properties also depend on the quality of the added aggregate, especially on its strength and hardness.
Basalt has shown a great potential to improve the impact resistance of UHPFRC, as the addition of a higher amount of this coarse aggregate has improved the UHPFRC impact behaviour.

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