Influence of Basalt Mesh Induced Increase of Heterogeneity of Cement Composites with Dispersed Fibers on Its Resistance under Near-Field Blast

J Zima¹ and M Foglar¹

¹ Department of Concrete and Masonry Structures, Czech Technical University in Prague, Faculty of Civil Engineering, Thákurova 7/2077, Prague, Czech Republic

E-mail: jakub.zima@fsv.cvut.cz

Abstract. This paper describes the influence of multiple basalt meshes in the cement composite specimens on the damage induced by near-field blast. Experimental measurements performed in the Boletice military area in 2014 and 2015 are evaluated by numerical simulations. The evaluation of the results is mainly focused on the stress propagation in the cement composite with dispersed fibers, the propagation of the overpressure caused by the blast and velocity of the ejected parts from the specimen. The influence of the presence and position of the basalt meshes in the specimen on its damage induced by delamination is also examined.

1. Experimental program

The experiments were performed in the Boletice military training area, in cooperation with the Armed Forces of the Czech Republic, in fall 2014 and 2015. The location and the layout of the experiment was very similar to the authors' previous experiments [1, 2, 3], though some improvements were gradually made to the layout. Two specimens in total were tested; consecutively named no. 17 and no. 18 with respect to the history of the experimental program. Specimens no. 17 and 18 were concrete slabs 6 m in length, 1.5 m in width and 0.3 m in thickness with the same amount of steel reinforcement, i.e. 11 pcs $\varnothing$ 16 mm reinforcing bars every 140 mm on both surfaces, $\varnothing$ 10 mm every 150 mm as an outer transverse reinforcement, and shear reinforcement was provided by $\varnothing$ 8 mm links (9 pcs/m²). Concrete cover of 50 mm was taken to the surface of the transverse reinforcement. Reinforcement arrangement was essentially the same as in [1, 2, 3]. The scheme of the experiment is shown in Fig. 1. The ground beneath the slabs was excavated to a depth of 2 m to avoid the results being influenced by the shock wave bouncing off the ground. 25 kg TNT charges were placed on steel chairs in the middle of each slab. The chairs provided 450 mm standoff from the slab. Information on the instrumentation used during the experiment can be found in Kovar et al. [4], Foglar et al. [5] and Hajek et al. [6].
Specimen No. 17 and No. 18 were made of ultra-high performance fiber-reinforced concrete (UHPFRC). Two types of high-strength steel (HSS) fibers were used: 35 mm in length and 13 mm in length. The yield strength of the fiber material is guaranteed by the manufacturer to be higher than 2200 MPa.

Specimens contained basalt fiber meshes in multiple layers along the depth of the specimen in distances about 50 mm (Fig. 2). The melting point of the basalt fibers is 1350 °C. The tensile strength of the basalt fabric was about 4200 MPa with a tensile modulus of elasticity of about 85 GPa. The unit weight of the mesh is 250 g/m$^2$ with weight density of 2.67 g/cm$^3$. Each string of the mesh consists of multiple fibers so the diameter of each string cannot be accurately defined. From parameters presented above, an effective area of each string equal to 1.4 mm$^2$ was calculated instead.

Figure 1. Specimen P19

Figure 2. Concrete details drawing Specimen No. 18
2. Numerical simulations

Numerical simulations were performed in ANSYS LS-DYNA software. Near-field blast was simulated with the build-in function Load Blast Enhanced which converts the blast load into pressure impulse. Using axis symmetry of the experiment, one quarter of the specimen is considered. Parameters of the used material correspond to the parameters of concrete with cylindrical compressive strength of 80 MPa. Individual parameters of concrete were introduced into the program using the cubic strength and fracture energy of the material model. High-performance concretes with a strength up to 120 MPa were used in experimental measurements. However, the material model used allows the setting of cylindrical compressive strength only 80 MPa [7, 8]. Nevertheless, this fact does not influence the outcomes of the numerical study, since the purpose is to study the effect of the basalt mesh layers, not the effect of the compressive strength of concrete.

Three types of numerical models were created:

- Model with reinforced concrete and dispersed fibers
- Model with reinforced concrete, dispersed fibers and one layer of basalt mesh at the soffit of the specimen in the half of the reinforcement cover
- Model with reinforced concrete, dispersed fibers and five layers of basalt meshes as seen in Figure 2

![Figure 3. Layout of basalt meshes, 1 layer at the soffit of the specimen in the half of the reinforcement cover](image)

For velocity evaluation of the ejected parts of the specimen and comparison with the experimental measurement, points were determined on the lower surface of the specimen. During the the experimental measurement, the points were measured in the middle of the specimen span, 150, 300 and 450 millimetres from the center. A specimen of five layers of basalt mesh was used for comparison of the experimental measurement and the numerical model. Numerical model with one layer of basalt mesh could not be compared with experimental measurement performed by the PDV device (see below), only macroscopic damage could be performed.

As can be seen in Figure 7, the velocity of the ejected parts in the middle of the span, 150 and 300 millimetres from the center do not correspond to the numerical models. This difference in velocity is mainly caused by the presence of the steel chair (on which the charge is placed). The chair behaves as a projectile, which is why the velocity of the scabbed parts is higher than in the places where there is no effect of the chair. For this reason, the numerical model could not be exactly compared with one layer of mesh in the points where the effect of the steel chair is predominant. The velocity of the flying debris only in the middle of the span was measured during the experimental measurement.
- Channel position CH1, Node 332, Coordinate [3000; 0; 0]
- Channel position CH2, Node 317, Coordinate [2850; 0; 0]
- Channel position CH3, Node 302, Coordinate [2700; 0; 0]
- Channel position CH4, Node 289, Coordinate [2550; 0; 0]

**Figure 5.** Experimental results for the specimen no. 18 – Damaged specimen; channel position scheme from the measurement

**Figure 6.** Position of the measurement points, view from the soffit of the specimen; measurement point are located at the centre-line of symmetry

In the following graphs, the influence of the basalt mesh layers in the specimen can be observed with respect to the velocity of the ejected parts and then the comparison with experimental measurements is performed.
Figure 7. Experimental and numerical results for the specimen no. 18

Figure 8. Velocity of the ejected parts, in the middle of the span

Figure 9. Velocity of the ejected parts, 450 millimetres from the middle of the span
The graphs indicate the effect of basalt meshes on the velocity of the ejected parts from the specimen. In the middle of the span and 150 millimetres from the center of the specimen, the velocity of the scabbed parts is higher. This effect is most probably caused by the influence of a flying steel chair. The half of the steel chair has size 250 millimetres. The measurement point 300 millimetres from the middle of the specimen is affected by the load distribution. At the measurement point where the velocity of the ejected parts is half compared to the measured points under the impact of the chair. The compliance with the experimental measurement at the measurement point was reached at a distance of 450 millimeters from the midpoint of the specimen span, because there is no direct influence of the steel chair on the velocity of the ejected parts.

Damage to the soffit has increased with the number of nets, the scabbed parts are smaller in size. This can increase the effectiveness in protection of persons.

In Figures 10 to 13, the initialization of the delamination of the specimen without, with one and with five basalt meshes can be observed. The difference of the material properties of the concrete and basalt causes internal reflection of the overpressure wave. The delamination of the specimen in numerical model is in good agreement with the results of experimental measurement. In the specimen without basalt mesh, the section is delaminated only at the steel reinforcement. In the specimen with one layer basalt mesh, delamination occurs in the area of the concrete reinforcement at the top surface and at the basalt mesh. At the specimen with five layers of basalt meshes, there is a clear delamination near all the basalt meshes. The delamination of the specimen with basalt meshes does not occur only around the plan center of the specimen, but it is distributed over a larger specimen area from the centre point of the blast loading.

![Figure 10. Specimen without basalt meshes – delamination at steel reinforcement](image1)

![Figure 11. Specimen with basalt mesh in the middle of the concrete cover, delamination of the specimen due to the placement of basalt meshed and at steel reinforcement](image2)
Figure 12. Specimen with five basalt meshes, delamination of the specimen due to the basalt meshes and steel reinforcement

Figure 13. Delamination of the specimen due to the presence of basalt meshes, experimental finding

Evaluation of the stress development in the specimen during the blast showed no influence of basalt meshes on the decreasing of compression on the upper face of the specimen. Stress values are practically identical in all measured points from blast initialization to $0.5 \text{ ms}$. From this time, the stress in evaluated numerical models starts to change. Course of the stress damping is similar for each numerical model but differs in the scale. Pressure in the measured points reaches the initial phase value of $80 \text{ MPa}$ which is considered as a strength limit for the material.
3. Conclusion
The increase of heterogeneity by addition of the basalt meshes into concrete can decrease the volume of concrete debris in the case of the blast. Placement of basalt reinforcements can reduce the velocity of the ejected parts. When comparing the velocity of the scabbed parts with experimental measurements, match can only be achieved at the measurement points where the steel chair does not interact with the specimen. The steel chair behaves as a projectile and the velocity of the scabbed parts at the impact site is several times higher. The basalt meshes increase heterogeneity of the material, increase the number of internal overpressure propagation rebounds and therefore helps to reduce the size of the ejected parts. The pressure in the specimen is not significantly changed by the basalt meshes. A further important step for precise modelling is the incorporation of the steel chair in the phenomenon, which significantly affects the extent of damage and the rate of the scabbed parts of the specimen at the point of its impact.

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