DEBRIS VELOCITY ASSESMENT OF FIBER CONCRETE SPECIMENS LOADED BY BLAST LOAD

*Ondřej Janota, **

Katedra betonových a zděných konstrukcí, Fakulta stavební,
České vysoké učení technické v Praze, Thákurova 7/2077, 166 29 Praha 6, Česká republika.
ondrej.janota@fsv.cvut.cz

ABSTRAKT

Předmětem tohoto příspěvku je shrnutí prezernace poznatků získaných v rámci experimentu zaměřeného na stanovení výbuchové odolnosti prvků z vysokohodnotného drákobetonu (dále UHPFRC). V rámci toho experimentu byla měřena rychlost spodního povrchu jednotlivých vzorků a následně porovnána. Byly tak získány grafy vývoje rychlosti těchto povrchů v případě všech tří módů porušení (prvek bez porušení, odštěpení spodního a horního povrchu, průraz). Vývoj rychlosti spodního povrchu je v rámci toho příspěvku ukázán na třech vzorových prvcích s výše uvedenými způsoby porušení. V závěru jsou experimentálně získané výsledky měření rychlosti spodních porvchů porovnány s daty uváděnými v literatůře. Toto porovnání je zaměřené zejména na mírů nebezpečnosti rychlosti vytržených částic pro blízké osoby.

KLÍČOVÁ SLOVA

Výbuchová odolnost • UHPFRC desky • rychlos výtrže• numerické modely • trhliny

ABSTRACT

This paper presents overview of the experimental measurement focused on the blast resitance of the ultra-high performance fiber reinforced composited specimens. Soffit velocity measurement was performed during the experiment. These velocity measurements were performed hand in hand with the video recording of the soffit. Three typical soffit velocity developement were obtained. Each for typical failure mode (No damage, spall and crated and breach). At the end, obtained velocity results were compred to the literature. Comparison is focused only on the debris danger to the human health.

KEYWORDS

Blast resistance • UHPFRC slabs • debris velocity • cracks

1. EXPERIMENTAL SETUP

Specimens were made of two proprietary UHPFRC materials with compressive strength 180 MPa (Premix A) and 150 MPa (Premix B). Amount and length of fibers in each concrete mixture were similar as well as other material characteristics. Specimen dimensions were 1000 x 1000 mm x 100, 150 and 200 mm. To eliminate the effect of the side reflection of pressure wave, the specimen proportions were numerically tested and evaluated as sufficient. The pressure wave reached the bottom side of the specimen and caused the damage under the blast charge sooner than it reached side sides and reflected.

To evaluate known approaches of RC and UHPFRC blast resistance prediction, different scaled distances were used for each experiment. The charge of SEMTEX 1A explosive varied from 100 g to 1000 g. Clear distance between slab's top surface and explosive varied from 0 mm (contact blast) to 100 mm (close-in blast). Each explosive was situated in the centre of the slab. Shape of the explosive was cylinder with dimeter/length ration equal to one. The detonation point was positioned approximately 20 mm below the top surface of blast charge.

Specimens were placed on a 720 mm high steel frame (Fig. 1). On the top, three steel plates were welded peripherally to avoid falling specimen from the steel frame during the blast. Supporting of the specimens with steel frame enabled considering boundary conditions as simply supported slab in both directions.

Fig. 1*: Specimen with the explosive charge and mirror under specimen.*

2. SPALL VELOCITY DEVELOPEMENT

Spall velocity was measured by the PDV device. Results from the measurement show velocity of spalling debris (i.e. spall

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* Školitel: doc. Ing. Marek Foglar, Ph.D.

velocity) during blast propagation (from the initiation of blast until destruction of the collimator). Results from the PDV were divided into groups according to their final failure modes. Three typical velocity development curves with their phenomena are presented.

In case that the failure mode was crater or no damage, then instead of spall velocity the bottom surface velocity was measured. Therefore, both collimators survived and both acceleration and deceleration of the surface were recorded. Figure 2 shows typical development of the bottom surface velocity.

Channel 1, measuring the centre of the specimen, indicated no movement until the pressure wave reached bottom surface. After that, approximately 0.14 ms after the explosion, rapid acceleration occurred. Time duration of this acceleration was almost infinitely small. After the velocity peak was reached, the surface starts to decelerate. The deceleration was, in comparison with the acceleration, gradual. Deceleration can be divided into two parts. From 0.1 ms to 0.22 ms the deceleration was slow. After that time the deceleration rate increased. Finally, bottom surface stopped moving. After that time, there was no significant movement.

Channel 2, which measured the area located 75 mm from the centre of the specimens, showed similar trend. The movement started at the exactly same time as the centre point. However, the acceleration was not so rapid, and the velocity peak was not so high. After that point the deceleration occurred. Up to approximately 0.20 ms, the deceleration rate was higher than in case of channel 1. In 0.20 ms the area started to accelerate again but the second peak value reached lower values. After the second velocity peak occurred, the surface started to decelerate again around 0.24 ms. From time 0.32 ms deceleration of both measured areas were equal. Side area measured by channel 2 stops moving in 0.5 ms.

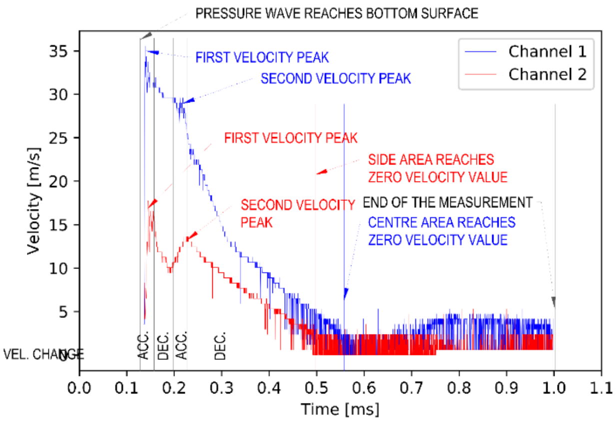

Fig. 2*: Typical bottom surface velocity for crater only/ no damage failure mode*

In case of the crater and spall failure mode was reached, the spall velocity development was similar to the development of velocity in case of only crater failure mode (Figure 3). After 0.14 ms the bottom surface started to rapidly accelerate. The velocity peak was immediately reached and the deceleration occurred. This part of deceleration lasted for about 0.15 ms and in 0.3 ms, area measured by channel two started to accelerate again. This acceleration was relatively small in comparison to main acceleration. After the second peak value was reached the area measured by channel 1 decelerated. This deceleration lasted for about 0.12 ms. Since then the velocity of centre part after the second deceleration was almost constant. However, there are parts of the curve where the velocity is constant it is not possible to precisely determine when the spall is fully ejected.

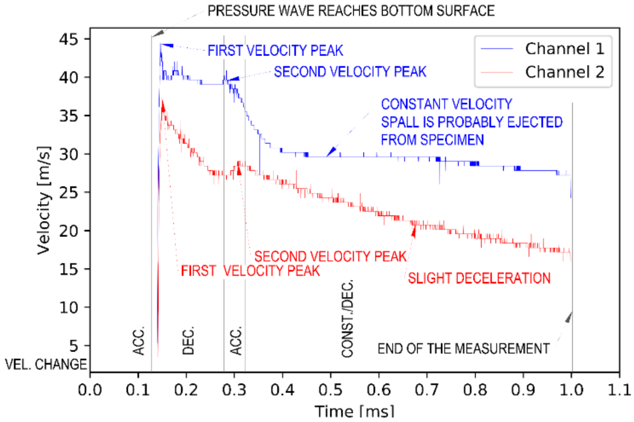

Fig. 3*: Typical spall velocity for crater and spall failure mode*

Development of spall velocity of breached specimens is relatively simple in comparison to the previous two failure modes (Figure 4). After the pressure wave reached the bottom surface, both measured areas rapidly accelerated and reached maximum velocity. Velocity of the spall was almost constant for the rest of the measurement. The measurement ended as the collimators were destroyed by the debris or measurement was manually stopped.

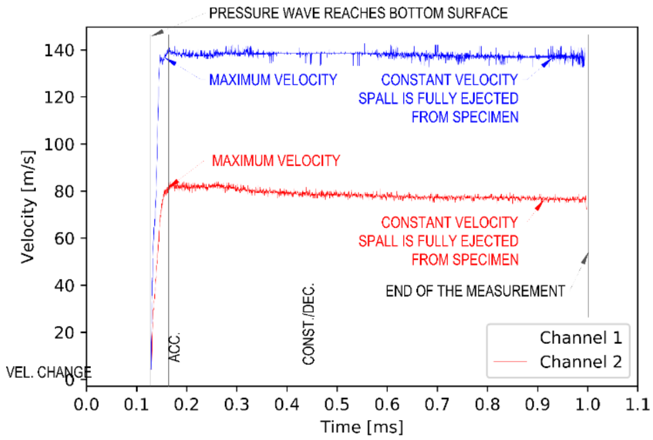

Fig. 4*: Typical spall velocity for breach failure mode*

Generally, the velocity development curve revealed following phenomena. The first velocity peak occurred immediately after the bottom surface was accelerated. This velocity was, in majority of the experimental results, the highest. In some cases, the highest velocity occurred after second or even third peak. This phenomenon can be caused by the wave reflection. If there was no spall, the bottom surface reached velocity peak and then decelerated in several phases. Each phase ended by further velocity peak. This peak, in most measurement, did not reach the values of the previous peak. Reason for this peak was probably multiple wave reflection at the edge of the specimen. Velocity development of the specimens with the crater and spall failure mode was similar to the only crater failure mode. However, in some cases the velocity stayed constant after one of the velocity peaks the ejection of the spall cannot be determined only from PDV results. In case of breach, the curve was relatively simple. After first velocity peak was reached, the velocity did not significantly decrease and stayed almost constant for the rest of the measurement

3. FINAL VELOCITY

Analysis of the final velocity of the spall was performed in similar manner as the maximum spall velocity analysis. Nevertheless, during the measurement final velocity of the debris is probably more important than the maximum velocity. Generally, there are two key factors that determine how severe the explosion is from the point of facility damage or human safety view. First factor is the overpressure magnitude and its duration. Second factor is velocity of the ejected fragments of the affected facility, equipment and barriers.

For better orientation literature was reviewed and debris velocities for different lethal probabilities and injury threshold were implemented to the presented figures. As the affected facilities can be made from different materials and the lethality of the debris does not solely depend on the velocity but also the weight of the debris must be taken into consideration. Graphs presenting lethal thresholds for debris based on their velocity and weight can be found in literature. These graphs show the impact on different parts of human body. These limits are presented in figure 5 and figure 6.

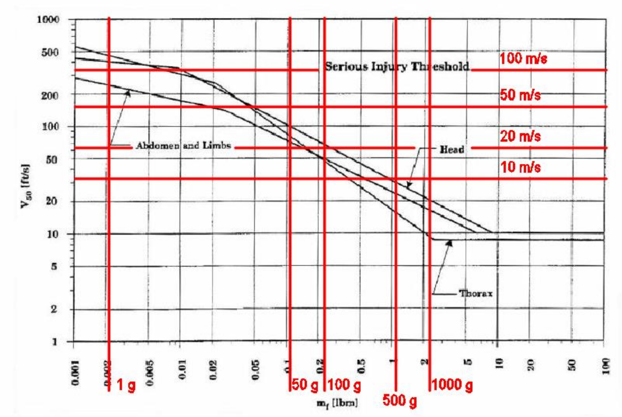

Fig. 5*: Typical bottom surface velocity for crater only/ no damage failure mode [1] [2]*

3.1. Influence of scaled distance on the final velocity

As well as in case of maximum velocity, the final velocity decreased with the increase of scaled distance. Four specimens with the scaled distance 0.13 - 0.18 m/kg1/3 and higher reached the final spall value 20 m/s and lower (figure 39). However, two specimens were without spall at all. Half of the specimens with the scaled distance 0.09 m/kg1/3 and lower also reached the final velocity lower than 20 m/s. However, as in case of maximum velocity, most of these specimens were with the thickness of 150 mm and 200 mm. If these results were eliminated and only 100 mm thick specimens were considered (figure 40), most of the specimens with lower scaled distance reached final spall velocity 80 m/s and higher for channel 1 and 30 m/s for channel 2. Development of the spall final velocity and its dependency on the scaled distance can be calculated by exponential function. R-values for these functions varied from 0.68 to 0.71 for both channels and both cases (all specimens, only 100 mm thick specimens).

Limits presented in figure 37 are implemented to the experimental results in figure 39 and figure 40 as well. Minimum debris velocity for 50% lethal probability of 50 – 1000 g debris were implemented to the figures. It is obvious that if the scaled distance was lower than 0.09 m/kg1/3 then even 50 g debris would be lethal. On the other side if the scaled distance was higher than 0.13 – 0.18 m/kg1/3 then even the 1000 g and 500 g debris did not reach the threshold for 50% lethal probability. However, it is important to emphasize that the distribution of debris weight was not measured. Velocities of debris were measured right after the blast and in very close distance from the soffit. It is probable that if measured further from the specimen, the velocity would decrease, and more results may drop under the 50% lethal line.

Debris weight - 1000 g				
Body part	**Severe injury treshold**	**Velocity [m/s]**		
Kill probability	-	**10%**	**50%**	**90%**
Limbs and abdomen	4.0	10.0	13.1	16.8
Head	5.5	8.5	10.1	11.9
Throax	3.0	8.2	10.0	11.3
Debris weight - 500 g				
Body part	**Severe injury treshold**	**Velocity [m/s]**		
Kill probability	-	**10%**	**50%**	**90%**
Limbs and abdomen	7.0	15.9	22.0	28.0
Head	9.2	14.3	16.8	20.4
Throax	5.8	10.0	12.8	18.3
Debris weight - 100 g				
Body part	**Severe injury treshold**	**Velocity [m/s]**		
Kill probability	-	**10%**	**50%**	**90%**
Limbs and abdomen	18.3	39.6	51.8	64.0
Head	21.3	32.0	39.6	48.8
Throax	15.9	30.5	42.7	57.9
Debris weight - 50 g				
Body part	**Severe injury treshold**	**Velocity [m/s]**		
Kill probability	-	**10%**	**50%**	**90%**
Limbs and abdomen	21.3	51.8	73.2	88.4
Head	29.9	48.8	53.4	62.5
Throax	25.9	51.8	61.0	86.9
Debris weight - 1 g				
Body part	**Severe injury treshold**	**Velocity [m/s]**		
Kill probability	-	**10%**	**50%**	**90%**
Limbs and abdomen	85.4	176.8	231.7	289.6
Head	182.9	219.5	274.4	>300
Throax	146.3	237.8	268.3	>300

Fig. 6*: Typical bottom surface velocity for crater only/ no damage failure mode*

3.2. Influence of the specimen thickness on the final spall velocity

Influence of the specimens' scaled thickness on the final spall velocity is presented in Figure 41. Increase of the scaled thickness above 0.24 m/kg1/3 decreased the final velocity for more than 50% in comparison with the specimens with the scaled thickness of approximately 0.14 m/kg1/3. Development of the final velocity can be described by the exponential function with very high R-values; 0.97 for channel 1 and 0.81 for channel 2.

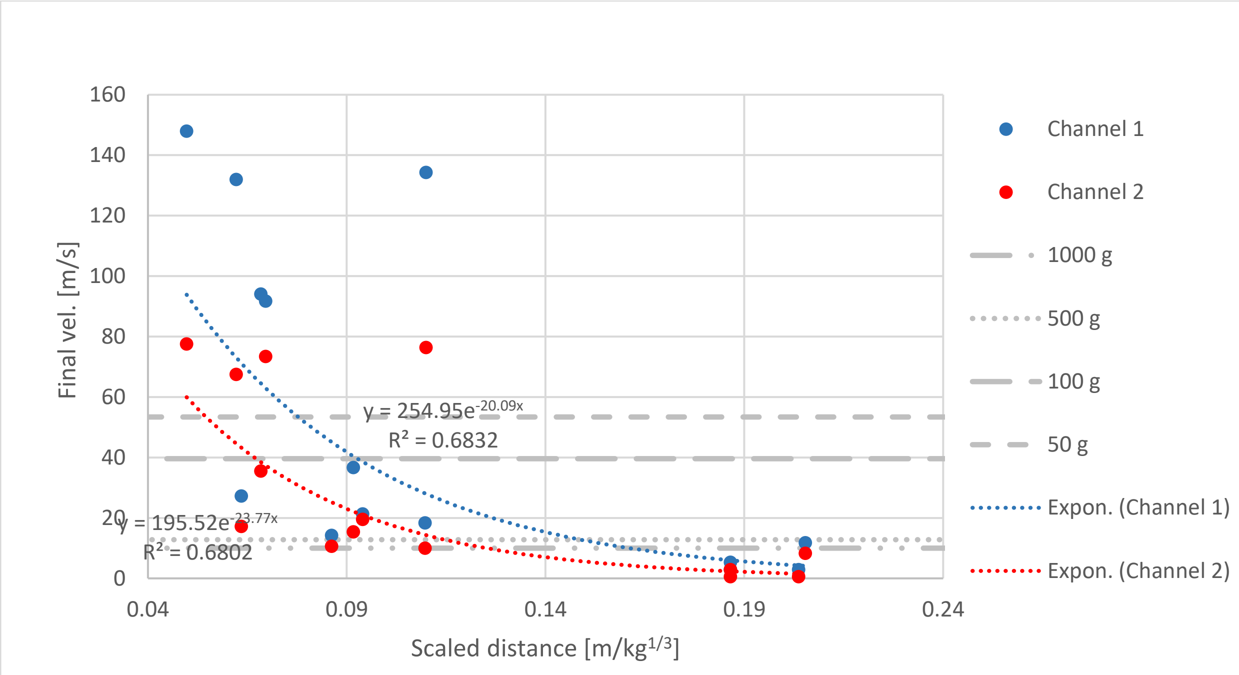

Fig. 6: *Final velocity development comparison (all specimens)*

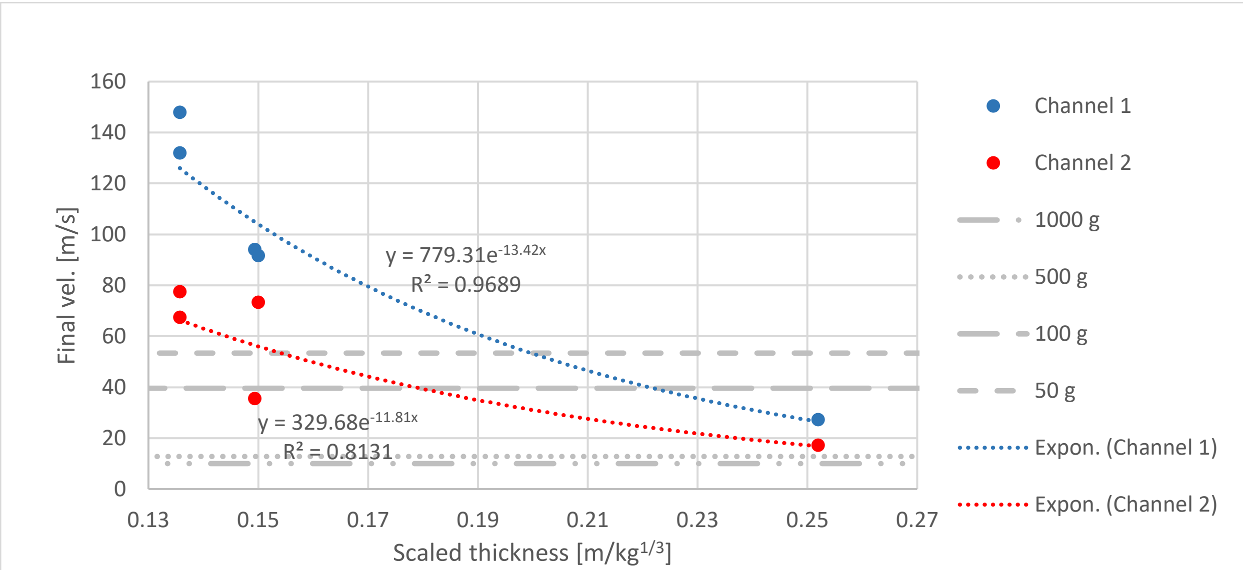

Fig. 7: *Final velocity development comparison (scaled thickness)*

CONCLUSION

Two types of UHPFRC were tested for their contact and close-in blast resistance. Materials with compressive strengths 180 MPa and 150 MPa were tested. The blast loading was created using SEMTEX 1A explosive. Weight of explosive varied from 100 g up to 1000 g. The distance between top surface and the explosive charge varied from 0 to 100 mm.

Presented results in this article were focused only on the evaluation of the soffit velocity. Velocity development of three different modes of were described in detail. Comparison with the data available in literature revelated values of the scaled distance and scaled thickness need for probability of health safety level.

Furthermore, influence of the experimental setup (specimen thickness and scaled distance) was evaluated.

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