The effects of a new steel fiber in concrete under small-caliber impact

M. Michal[1], M. Keuser[1] & C. Frey[2]
[1]*Universerstät der Bundeswehr, Germany*
[2]*Feel Fiber GmbH, Germany*

Abstract

Military facilities, buildings such as embassies or nuclear power plants must be protected against effects and impacts from terrorist attacks or accidents. In the course of new building or upgrading existing structures the protective function against gun fire or debris due to explosions should be fulfilled with small dimensions. The main material property influencing the resistance against these threats is the tensile strength. By adding steel fibers post-cracking behaviour and ductility of components can be improved.

A new type of steel fiber has been tested for application in construction elements under high loading rates. Protection shields have been produced and the effect of small caliber gun fire has been investigated. The tests on concrete shields showed a considerably reduced crater dimension and reduced raptures. By using steel fibers the endangerment of persons and facilities by debris can be reduced.

With the tests the positive influence and the fundamental suitability of the new long fibers could be confirmed. A possible application would be the usage for barriers or modular systems made of precast concrete or hardening of existing structures.

Keywords: steel fiber, protection shield, small calibre gun fire.

1 Introduction

Impact on concrete structures is characterised by local damage. The concrete in the area directly affected by the impactor is pushed aside with high velocity. Fragments are thrown out of the front side of the target [1]. The reflected wave can lead to scabbing on the rear side of the protection shield (Figure 1).

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Resulting debris can cause harm on persons or equipment. In Kustermann *et al.* [2] the influence of different concrete mixtures were investigated. While failure on the front side is determined by high local pressure, the rear side fails by tensile stresses due to the reflected wave. The choice of aggregates and reinforcement has a great influence on the required properties of the protective component.

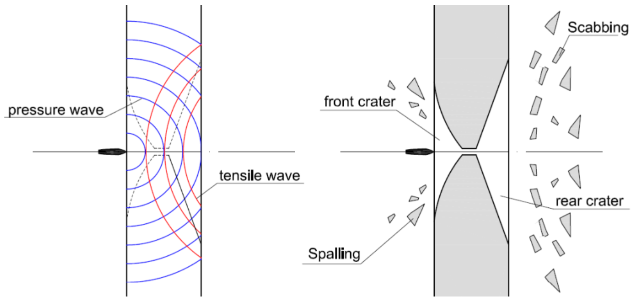


Figure 1: Schematic drawing of projectile impact.

Compressive and tensile strength of concrete are increasing with increasing strain rate. Some of the reasons for this strain-rate effect have been identified by Curbach [3] as the crack velocity, stress distribution and failure of aggregates. In drop tower tests with different slabs by Hummeltenberg *et al.* [4] the slabs with steel fibers were particularly suitable to resist impact.

In different tests conducted by EMI/UniBw and from in Literature with fiber reinforced concrete (FRC) under high strain rates no remarkable difference on the dynamic increase of tensile strength compared to plain concrete (Figures 2 and 3) was found. The same formulas used to describe the DIF for plain concrete (PC) can also be applied for FRC. The advantage of FRC over PC is the post-cracking behaviour. The concrete behaves in a more ductile manner and there´s still a residual load capacity left after cracking.

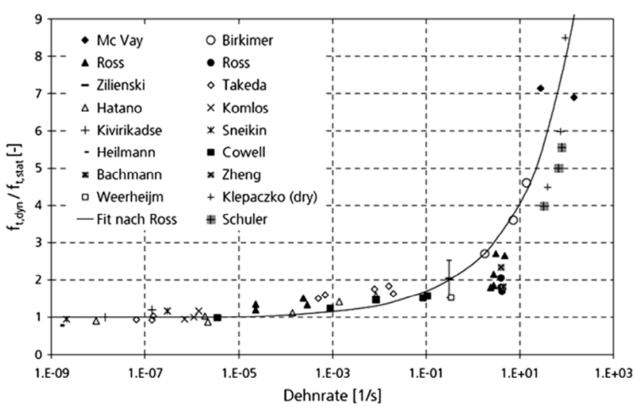


Figure 2: DIF for tensile strength of plain concrete [1].

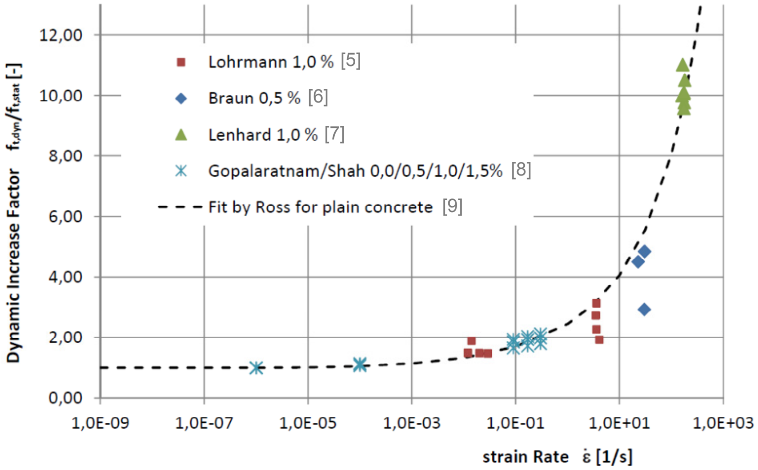


Figure 3: DIF for tensile strength of fiber reinforced concrete (FRC).

With the gun fire tests the effect of varying the steel fiber content on the extent of debris and failure of the protection shields should be evaluated.

2 Test method

2.1 Test equipment

The gun fire tests could be performed at the laboratory of the Department of Mechanical Engineering, Weapons Technology and Materials Science at the University of the Bundeswehr Munich (UniBW). For model tests twelve plates with dimensions of 50 cm x 50 cm x 8 cm were manufactured. With this dimensions it was possible to make two hits on the fiber reinforced plates. Without fibers the plates broke after the first hit (Figure 7). The plates were mounted in a steel frame and placed into a backstop. To determine the residual energy, steel sheets (St 37) have been fixed behind the concrete plate (Figure 4). The plates were exposed to gun fire by ammunition for a Russian sniper rifle Dragunov (armor-piercing bullet 7.62 x 54R, bullet weight ~ 10.4 g). The gun fire tests have been performed from a distance of 12 m. The projectile velocity was about 825 m/s.

Material properties for the panels were obtained from static tests at the UniBW and tests with a Hopkinson-Bar at the Fraunhofer Ernst-Mach-Institute in Efringen-Kirchen.

The measurement of projectile velocity was carried out via light barriers which were placed after the gun and right before the target. The velocity after penetration has been determined with high speed photos, taken at the rear side of the plate (Figures 5 and 8).

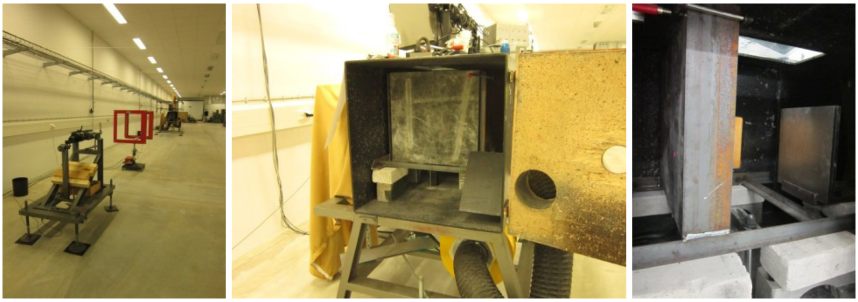


Figure 4: Shooting range (left), panel mounted in the backstop (center), panel and steel sheets (right).

Figure 5: Measurement of projectile velocity by light barriers (left, center) and optical (right).

2.2 Preparation of the specimens

The preparation of the specimens was carried out in the laboratory of the Institute of Structural Engineering at the UniBW (Figure 6). Beside the plates for the gun fire tests, specimens to determine static and dynamic material properties were built. Cylinders for tests on a Hopkinson-Bar were drilled out of concrete blocks [6].

Figure 6: Manufacturing of specimens in the laboratory of Structural Engineering of the UniBW Munich.

After removing the formwork, the specimens were stored under water until the tests.

2.3 Evaluation

For the description of the damage in the plates the following points were recorded:

- Front and rear side of the plates were photographed
- Crater diameter, depth and volume were measured
- Debris was collected and weighed
- The crater profile was recorded using a measuring rule
- The damage was recorded in main points

Figure 7: Typical damage pattern of plate with 0% fiber content (left) and plate with 0.5% fiber content.

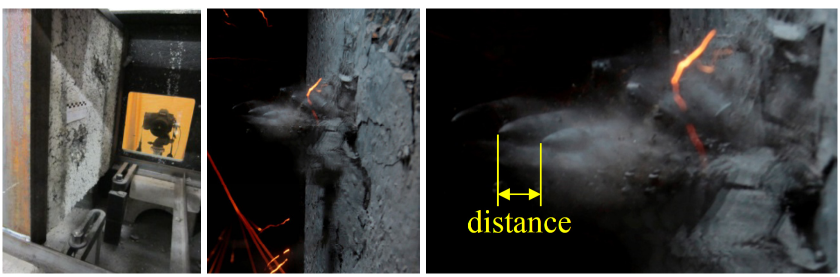


Figure 8: Optical measurement of residual projectile velocity.

3 Test programme

3.1 Concrete mixes

For the tests a concrete mixture similar to the type HFB_s_qu in Bludau *et al.* [10], where the influence of different concrete aggregates has been investigated, was used [11]. Four types of plates were produced with different contents of steel fibers within the range of 0.0% to 2.0%.

Table 1: Composition of concrete, maximum grain size d_g = 16 mm.

Cement CEM I 42.5 R-HS		297.00	kg/m³
w/b-ratio		0.34	[-]
Aggregates	0–2 mm	353.47	kg/m³
	2–8 mm	708.80	kg/m³
	8–16 mm	710.12	kg/m³
Fly ash		135.00	kg/m³
Silica fume		36.00	kg/m³
Flow improvers		13.37	kg/m³
Water (with dry aggregates)		121.64	kg/m³

Table 2: Hardened concrete properties with the herein used steel fiber content.

Fiber content (Feel Fiber)	Density	Compressive strength	Splitting tensile strength	Static Young's modulus	Dynamic Young's modulus
[%]	[kg/dm³]	[N/mm²]	[N/mm²]	[N/mm²]	[N/mm²]
0.0	2.475	99	6.34	43300	47400
0.5	2.495	79	5.73	43300	42200
1.0	2.505	94	8.34	41500	42700
2.0	2.545	93	8.4	-	-

3.2 Steel fibers

For the experiments fibers with the manufacturer's name FF-50/72-SH-5.01 (length: 50 mm, diameter 0.72 mm, S = Steel, H = 1400 N/mm² tensile strength, 5 = 5 anchor nodes, .01 = variant of the anchor node size) produced by steel fiber GmbH were used.

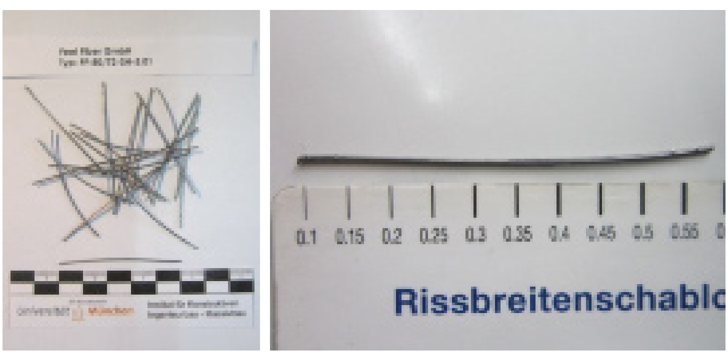


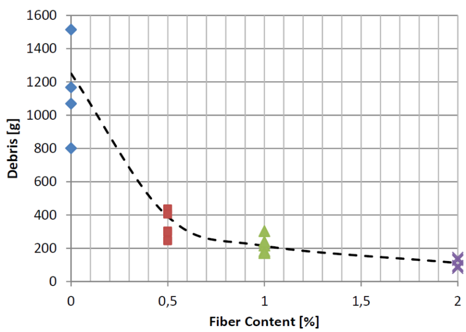
Figure 9: Feel fiber GmbH, type FF-50/72-SH-5.01.

The fibers are manufactured in an innovative technique, where band steel is grooved on both sides and then flex-leveled until the band fractures. This method is consuming less energy and more cost-effective then previous manufacturing processes. CO_2-emissions can be reduced significantly.

Anchor Nodes at the fiber improve the bond between steel and concrete.

4 Results

The debris from the front and rear crater was collected and was weighed after every gun shot. Afterwards the volumes of the front and rear crater were determined separately by filling them with quartz sand. With the known bulk density it was possible to calculate the respective volume. With both methods, a remarkable decrease of debris with increasing fiber content was found. This effect was most noticeable for the rear crater, where for the 2% FRC nearly no crater volume was left.



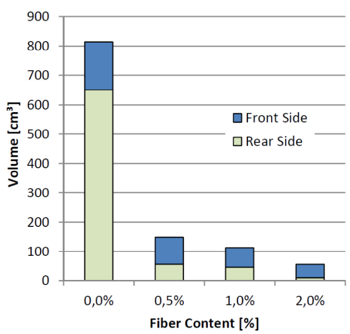


Figure 10: Concrete debris and crater volume subject to fiber content.

Under consideration of the cracks visible in the cross section (Figure 11), the failure-surface for all specimens showed a similar geometry. The diameter of the front crater was in a range from 100 to 200 mm with an angle about 23 degrees. For the rear crater a diameter about 150 to 250 mm with an angle about 20 degrees was determined. Especially for the 2% FRC very small crack widths about 0.1 mm were measured. The initial crack formation starts when the reflected tensile wave exceeds the tensile strength of concrete. Fragments and debris are sewed together in the post-cracking stadium and additional energy is dissipated by deformation of the steel fibers.

The resistance against gun fire and the protection against debris increased, with increasing fiber content.

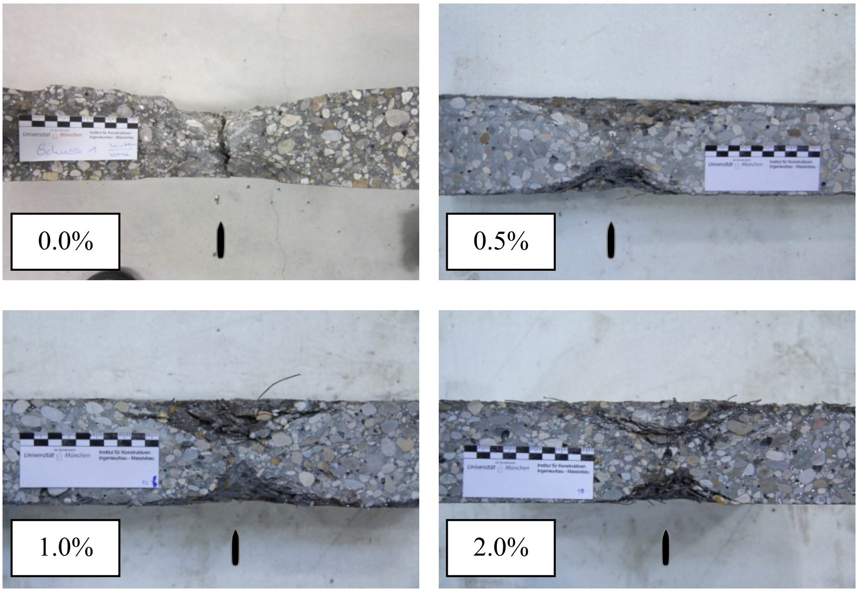


Figure 11: Cross section.

5 Conclusions

The tests showed hardly any influence of the fibers on static or dynamic tensile strength of concrete. However, in the gun fire tests a significant reduction of visible crater diameter and debris for the plates with fibers provided by feel fiber GmbH could be noted. Thus the risk for persons and furnishing by debris can be reduced to a considerable extend.

In further steps fracture-mechanical methods should be used for a better assessment of the dynamic post-cracking behaviour and ductility of FRC. The concrete mix will be optimized to improve the workability with the steel fibers.

With the experiments the positive influence and the suitability of the new long fibers for use in protection components could be shown. A possible application would be for barriers and modular systems in prefabricated concrete or for reinforcing existing structures.

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References

[1] Fuchs M., Keuser M., Schuler H., Thoma K., *Faserbeton unter hochdynamischer Einwirkung,* Beton und Stahlbetonbau 102, Heft 11, pp. 759–769 (2007).

[2] Kustermann A. *et al.*, *Hochfeste Bindemittel und Zuschlagstoffe für hochfeste Betone unterschiedlicher Güte für Schutzanlagen der militärischen Infrastruktur,* Berichte aus dem Konstruktiven Ingenieurbau, Universität der Bundeswehr München (2006).

[3] Curbach M., *Festigkeitssteigerung von Beton bei hohen Belastungsgeschwindigkeiten,* Schriftenreihe des Instituts für Massivbau und Baustofftechnologie, Universität Karlsruhe, Heft 1 (1987).

[4] Hummeltenberg A. *et al., Betonplatten unter Stoßbelastung – Fallturmversuche,* Beton und Stahlbetonbau 106 , Heft 3, pp. 106–168 (2011).

[5] Lohrmann G., *Faserbeton unter hoher Dehngeschwindigkeit*, Dissertation, Universität Fridericiana zu Karlsruhe, (1998).

[6] Braun A., *Material unter hochdynamischen Belastungen,* Bachelorarbeit, Universität der Bundeswehr München, not published (2014).

[7] Lehnhard S., *Faserbeton unter hochdynamischer Belastung,* Diplomarbeit, Universität der Bundeswehr München, not published (2006).

[8] Gopalaratnam V.S., Shah S.P., *Strength, Deformation and Fracture Toughness of Fiber Cement Composites at Different Rates of Loading,* Proceedings of US-Sweden Seminar, Elsevier Applied Science Publishers, U.K. pp. 299–331 (1986).

[9] Ross A.C., *Split-Hopkinson Pressure Bar Tests,* Final Report, Engineering & Services Laboratory, AFESC, Tyndall Air Force Base, Florida,(1989).

[10] Bludau Ch., Keuser M., Kustermann A., Thienel K.-Ch., *Schutzplatten aus hochfestem Beton,* Berichte aus dem Konstruktiven Ingenieurbau, Universität der Bundeswehr München (2006).

[11] Arnpothong N., *Beschussversuche an Elementen aus Stahlfaserbeton,* Bachelorarbeit, Universität der Bundeswehr München, not published (2014).