Flexural Performance Evaluation of Basalt and CEM-FIL Minibars™ Fiber Reinforced Concrete

Final Report

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by

Construction and Building Materials Research Center

The Science and Technology Research Institute (STRI)

King Mongkut's University of Technology North Bangkok

for

Infinity Wealth Futures Co., Ltd.

October 2019

Research Title:

Flexural Toughness Evaluation of Basalt Minibars^{TM} and CEM-FIL Minibars^{TM} Fiber Reinforced Concrete

by

Assoc.Prof. Manote Sappakittipakorn

Department of Civil Engineering, Faculty of Engineering

King Mongkut's University of Technology North Bangkok

for

Infinity Wealth Futures Co., Ltd.

87/1 Capital Tower, All Seasons Place, 10th Floor,

Wireless Road, Lumpini, Pathumwan, Bangkok 10330 THAILAND

Research Contract:

STRI 3582/2561

Note:

Infinity Wealth Futures Co., Ltd. as the research fund provider fully has the right to take and manage the commercial benefits from the results of the study.

Executive Summary

This research project aims to experimentally evaluate the Basalt and CEM-FIL Minibars fiber on the flexural performance on C25/30 grade concrete. Two fiber dosages of 5 and 10 kg/m^3 were employed. The influence of the Minibars fiber was compared with plain concrete. Three testing standards, i.e. EN 14651, ASTM C1609, and JSCE SF-1, were followed. Prior to the tests, all specimens were moist cured for 28 days. According to the test results, the Basalt and CEM-FIL Minibars clearly provide the flexural performance at the post crack state of cementitious matrices. For the fiber dosage of 5 and 10 kg/m^3 examined in this study, the higher the fiber dosage, the higher the residual strength. In case of C25/30 grade concrete, it is noticed that both Minibars produce deflection-softening behaviour – the residual strength after cracking is lower than the peak strength. At the broken section, most of the Minibars were slipped out of concrete. It is suggested that concrete strength should be increased to improve the interfacial bond between fiber and matrix. This will fully employ the fiber capacity and yield better flexural performance.

S.Manote

(Manote Sappakittipakorn)

Department of Civil Engineering

Faculty of Engineering, KMUTNB

1. Project Objective

To evaluate the performance of Basalt Minibars™ and CEM-FIL Minibars™ fiber on the flexural toughness and strength enhancement in concrete.

2. Scope and Experimental Plan

The details of experimental plan proposed are described as follows.

2.1. Materials and Test Apparatus

2.1.1. Two types of fibers (Basalt MiniBars™ and Cem-Fil MiniBars™) provided by Infinity Wealth Futures Co., Ltd. were evaluated in this project. Their specification are listed in Table 1.

Table 1 Specification of fibers used in this study (data from ReforceTech)

Fiber	Diameter (mm)	Length (mm)	Aspect Ratio	Elastic Modulus (GPa)	Tensile Strength (MPa)
Basalt Minibars™	0.65	43	66	44	>900
CEM-FIL Minibars™	0.65	43	66	44	>900

2.1.2. A typical C25/30 plain concrete was employed as a reference. Its mix proportion is shown in Table 2. It was made with a 180-Liter drum mixer (free fall). For fiber reinforced concrete mixes, fibers were gradually added to the plain concrete after mixed thoroughly. Then, the mixing was continued for another 2 minutes to ensure a uniform fiber distribution. To evaluate the fiber performance, the fibers were varied as shown in Table 3

Table 2 Mix proportion of plain concrete (kg/m^3)

Portland Cement	Water	River Sand	Crushed Limestone	w/c	Slump (mm)
323	194	838	1013	0.62	100 ± 25

Table 3 Mix code and variation of fiber (fiber density is 2,100 kg/m^3)

Mix No.	Code	Fiber Dosage (kg/m^3)	
		Basalt MinibarsTM Fiber	CEM-FIL MinibarsTM Fiber
1	OPC		
2	BF05	5.0	
3	BF10	10.0	
4	CF05		5.0
5	CF10		10.0

Noting that OPC is ordinary plain concrete, BF is Basalt Minibars^{TM} fiber, and CF is CEM-FIL Minibars^{TM} fiber

2.2. Testing of fiber reinforced concrete samples

2.2.1. Flexural performance as per EN 14651, ASTM C1609, and JSCE-SF4

2.2.2. Compressive strength as per ASTM C 39 (3 sample replicates)

Note: Above tests were conducted after moist cured for 28 days

2.2.3. Slump test for workability as per ASTM C 143

3. Reviews of Minibars^{TM} Fiber Performance

Since both Basalt Minibars^{TM} and CEM-FIL Minibars^{TM} have been in a market worldwide for many years, they were subjected to many tests on their flexural performance in various countries. Two recent report provided by the fiber company were reviewed here as follows.

3.1. Influence of dosage on flexural strength for different classes of concrete strength

The first report, which was issued in January 2018 by OCV Chambery International (Owens Corning) in France, focused only on AR Glass (CEM-FIL) Minibars^{TM} 43 mm. It examined the fiber dosage influence on flexural strength of several classes of concrete strength (C25/30, C30/37, C45/55, and C70/85). The test was carried out as per EN14651. Considering the C25/30 concrete that is similar to the one employed in the present project, the fiber dosage was varied at 5, 10, and 17 kg/m^3 and the influence of each dosage level on flexural strength is shown in Figure 1.

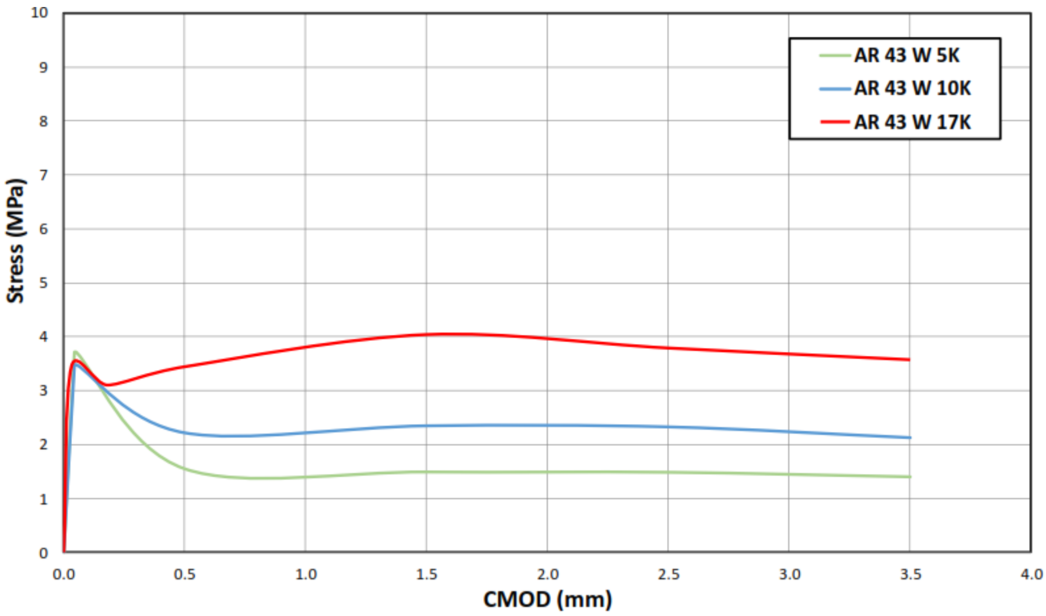
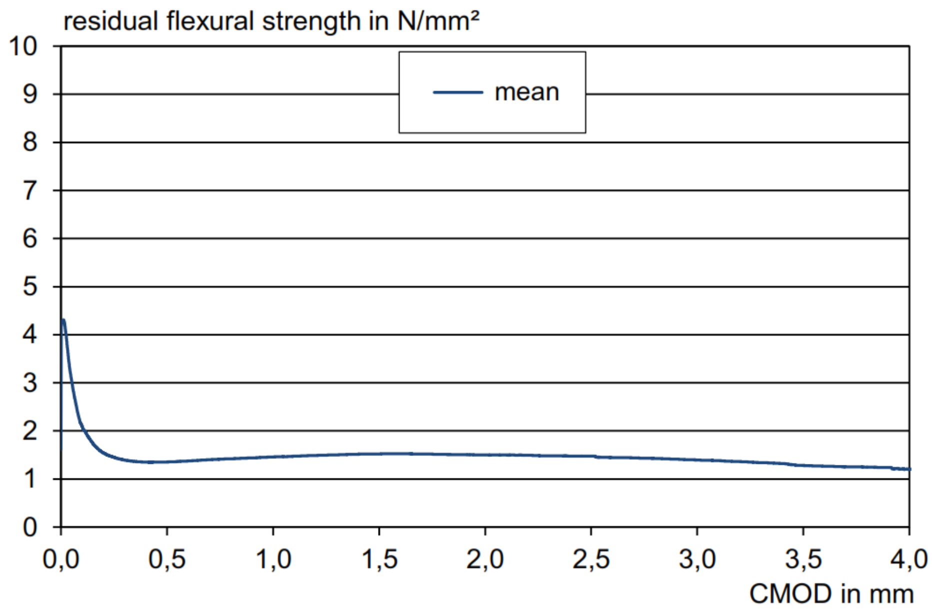


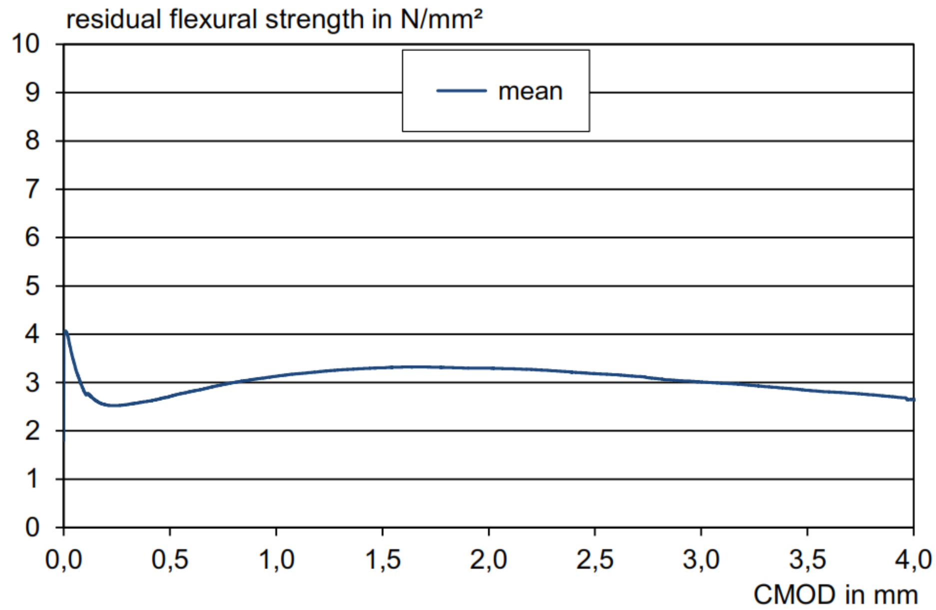
Figure 1 Flexural strength vs CMOD of C25/30 concrete reinforced with CEM-FIL Minibars™ 43 mm at the dosage of 5, 10, and 17 kg/m^3

3.2. ReforceTech Minibars™ characterization data overview

The second report was conducted in April of 2016 by RWTH Aachen University, Germany. Three types of fiber, i.e. AR Glass Minibars™ 55mm, Basalt Minibars™ 43 and 55 mm, at 4 fiber dosages (5.25, 10.5, 21, and 52.5 kg/m^3) were examined on the C25/30 and C50/60 concrete. Only are the Basalt MinibarsTM at 5.25 and 10.5 kg/m^3 with C25/30 concrete taken into consideration. Their three-point bending test results are shown in Figure 2.



(a) fiber dosage of 5.25 kg/m^3



(b) fiber dosage of 10.5 kg/m^3

Figure 2 Flexural strength vs CMOD of C25/30 concrete reinforced with Basalt Minibars^{TM} 43 mm at the dosage of (a) 5.25 kg/m^3 and (b) 10.5 kg/m^3

From the two reports reviewed above, the residual flexural strength at several specific crack mouth-opening displacements (CMODs) can be summarized in Table 4. It is expected and believed that the present project here in Thailand will obtain the same results to those remarkable findings.

Table 4 Summary of residual flexural strength of CEM-FIL Minibars™ and Basalt Minibar™ fiber reinforced concrete (based on the reports reviewed)

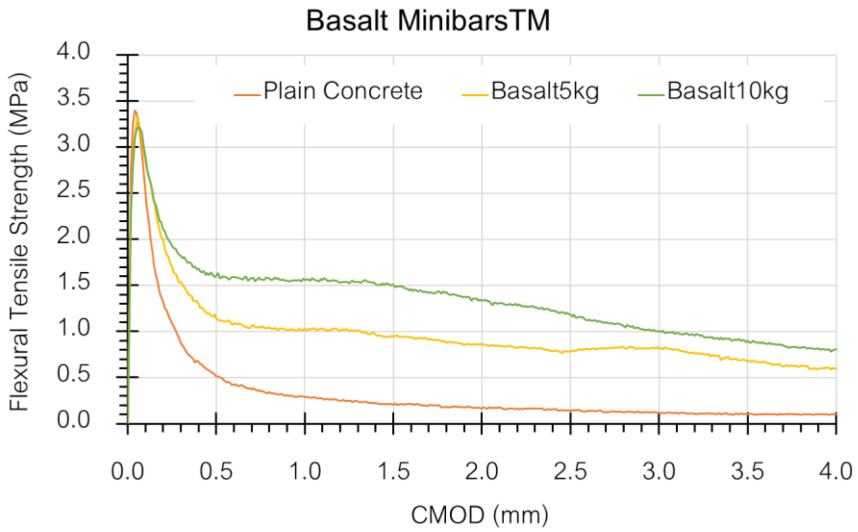
Mix#	Dosage (kg/m^3)	f_{LOP} (MPa)	$f_{R,1}$ (MPa)	$f_{R,2}$ (MPa)	$f_{R,3}$ (MPa)	$f_{R,4}$ (MPa)
CEM-FIL Minibars™	5	3.70	1.65	1.50	1.50	1.40
	10	3.50	2.25	2.35	2.30	2.15
Basalt Minibars™	5.25	4.35	1.35	1.52	1.47	1.28
	10.5	4.12	2.71	3.31	3.19	2.84

Note: f_{LOP} is the flexural strength at the limit of proportionality
$f_{R,1}$ is the residual flexural strength at the CMOD of 0.5 mm
$f_{R,2}$ is the residual flexural strength at the CMOD of 1.5 mm
$f_{R,3}$ is the residual flexural strength at the CMOD of 2.5 mm
$f_{R,4}$ is the residual flexural strength at the CMOD of 3.5 mm

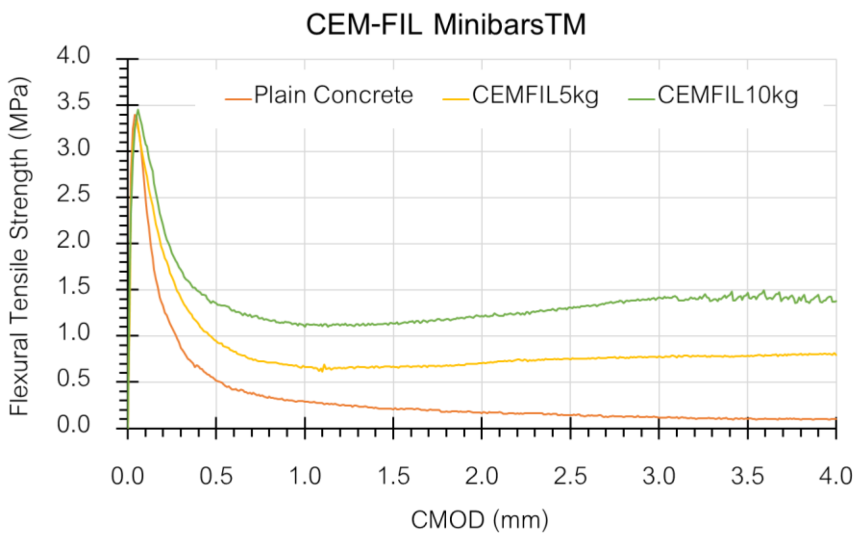
4. Test Results on Flexural Performance

4.1. Flexural Tensile Strength (EN 14651)

Regarding the EN 14651 standard test, the 150x150x600-mm beam specimen was subjected to the three-point loading – one at the middle and the other two at its end supports. A saw-cut notch was introduced on the beam tension surface to direct a crack initiation. The opening of the notch (called crack mouth opening displacement, CMOD) was controlled with a specific rate while the load applied at the middle was monitored until the CMOD reached at least 4 mm. Then the flexural tensile strength calculated from the applied load was plotted together with the corresponding CMOD as shown in Figure 3. The initial peak at the CMOD of 0.05 mm approximately provided the flexural strength for the limit of proportionality (f.LOP). Furthermore, at CMOD of 0.5, 1.5, 2.5, and 3.5 mm, the flexural strength determines the residual strength. They are then illustrated in Figure 4

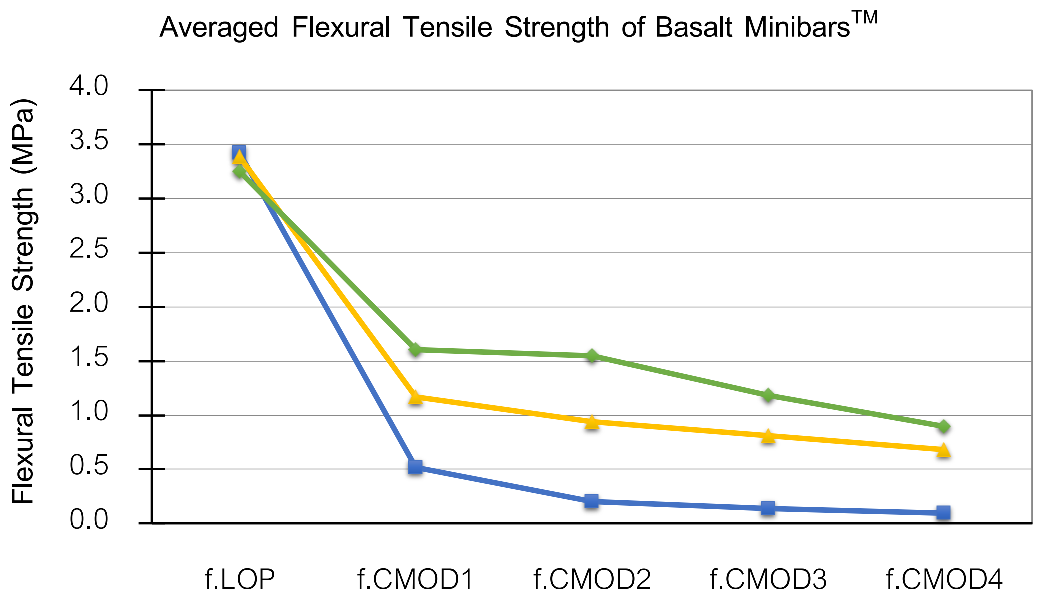


(a)

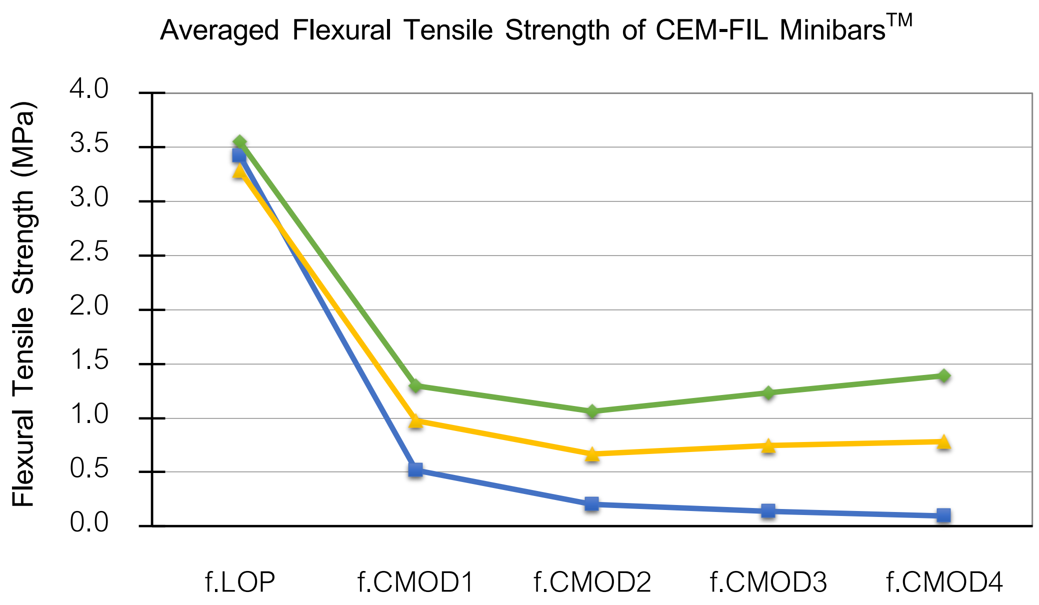


(b)

Figure 3 Flexural tensile strength as per EN 14651 for C25/30 grade concrete reinforced with (a) Basalt Minibar and (b) CEM-FIL Minibar



(a)



(b)

Figure 4 Flexural tensile strength at specific CMOD of concrete grade C25/30 reinforced with (a) Basalt Minibars™ and (b) CEM-FIL Minibar™ (43 mm) at the dosage of 5 and 10 kg/m^3

4.2. Residual Flexural Strength and Toughness (ASTM C1609 and JSCE SF-1)

This section describes the results of flexural strength and toughness of fiber reinforced concrete. Specimens were 150x150x500 mm prisms tested under four-point bending. The load applied provides flexural strength. It is then plotted with the net deflection of the specimen as shown in Figure 5. The area under the load and net deflection curve provides flexural toughness. Parameters indicating flexural performance of C25/30 grade concrete reinforced with Basalt and CEM-FIL Minibars according to ASTM C1609 and JSCE SF-1 are reported in

Table 5 and Table 6 respectively.

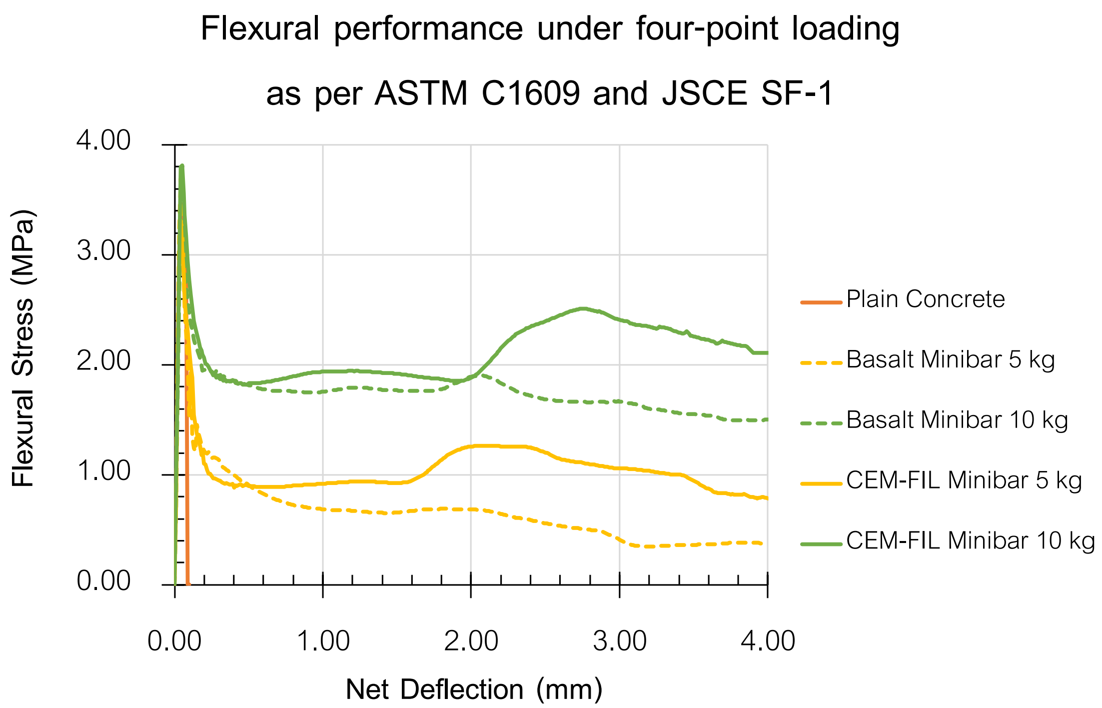


Figure 5 Test results of flexural strength vs net deflection under four-point loading on concrete grade C25/30 reinforced with Basalt and CEM-FIL Minibar

Table 5 Parameters for flexural performance evaluation as per ASTM C1609

ASTM C1609	Plain	Basalt Minibar		CEM-FIL Minibar	
	Concrete	5 kg	10 kg	5 kg	10 kg
First Peak Strength, f_1 (MPa)	3.17	3.44	3.31	3.05	3.81
Peak Strength, f_P (MPa)	3.46	3.69	3.31	3.32	3.81
Residual Strength, f^D_{600} (MPa)	0.00	0.75	1.76	0.89	1.88
Residual Strength, f^D_{150} (MPa)	0.00	0.41	1.67	1.06	2.41
Toughness, T^D_{150} (J)	1.62	17.37	40.68	24.77	46.84

Table 6 Parameters for flexural performance evaluation as per JSCE SF-1 standard

JSCE SF-1	Plain	Basalt Minibar		CEM-FIL Minibar	
	Concrete	5 kg	10 kg	5 kg	10 kg
Flexural Strength (MPa)	3.46	3.69	3.31	3.32	3.81
Flexural Toughness (MPa)	1.62	17.37	40.68	24.77	46.84
Flexural Toughness Factor (MPa)	0.07	0.77	1.81	1.10	2.08

5. Summary

According to the test results, Basalt and CEM-FIL Minibars clearly provide the flexural performance at the post crack state of cementitious matrices. For the fiber dosage of 5 and 10 kg/m^3 examined in this study, the higher the fiber dosage, the higher the residual strength. In case of C25/30 grade concrete, it is noticed that both Minibars produce deflection-softening behaviour – the residual strength after cracking is lower than the peak strength. At the broken section, most of the Minibars were slipped out of concrete. It is suggested that concrete strength should be increased to improve the interfacial bond between fiber and matrix. This will fully employ the fiber capacity and yield better flexural performance.