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Influence of Casting Direction on Fracture Energy of Fiber-Reinforced Cement Composites

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Abstract. This project investigated behavior of fiber reinforced cement composites in dependence on the casting direction. Almost fifty prismatic samples of size 400 x 100 x 100 mm were cast into moulds; half of these were fiber reinforced concrete FRC and the other half was ultra-high performance fiber reinforced concrete UHPFRC. Half of samples of both materials were cast in the common horizontal direction and the other half in the vertical way. It was found that fracture energy of horizontally cast prisms was approximately 4,5 times higher in both cases than the vertically cast ones. The ultimate loads of FRC were very similar for both ways of casting. On the other hand the peak loads of horizontally cast UHPFRC prisms were approximately 3 times higher than the vertically cast ones.

Introduction

The cement based composites reinforced by steel fibers are well known for almost fifty years. In the 1960´s Romualdi et al. [1,2] published their first papers about steel fiber reinforced concrete. The presence of fibers also improve the resistance of composite material to shrinkage during the hardening process, the fire and impact resistance and ductility [3,4]. The characteristics of the composite are affected by many influences e.g. dimensions, material and amount of fibers, type of cement, aggregate etc. The shape, size and type of material of the fibers play an important role for distribution and orientation of fibers. The behavior of matrices of these cement composites tend to be more brittle with the increasing compressive strength [5]. In general the distribution of fibers in fiber reinforced composite is assumed more or less as uniform, homogenous and isotropic. Nevertheless it was observed that these predictions cannot be always guaranteed. The orientation of fibers in concrete is essential for its final properties. In his paper, DEEB et al. [6] was examining the orientation of short steel fibers during the flow of self-compacting concrete mix. The behavior of concrete reinforced with fibers was studied using simulated flow model. The fibers had a tendency to remain randomly oriented perpendicular to the direction of flow of the mixture. The same conclusion made VANDEWALLE et al. [7] and in this paper the orientation was attributed to wall effect of the mould, which was reorienting of flow of the concrete mixture. In this paper it was also stated that from specific distance, fibers weren't reoriented anymore and fibers continued to maintain their current position. The influence of the way of casting, the size and shape of mould should be taken into account [8]. The uniform orientation and distribution of the fibers can be assumed only for large members with the fibers tend to straighten along the mould. Also there was observed by Soroushian et al. [9] that vibration reorients the fibers in the horizontal direction. This effect with the casting direction can have very large influence on the tensile capacity and the fracture energy of the structural members. The average fracture energy of bent prism according to RILEM recommendation [10] can be calculated as a total work divided by projected fracture area:

$$G_f = \frac{1}{(d-a)\cdot b}\int F(w)dw$$

(1)

with

G_f	is fracture energy,	b	is width of the sample,
d	is height of the sample,	$F(w)$	is load function,
a	is depth of the notch,	w	is displacement.

Characteristics of FRC and UHPFRC and Process of the Casting

The compositions of mixtures used in this study are stated in the Table 1. These mixtures are based on the research of the FRC and UHPFRC resistance to the impact loading which was published in [11]. Almost 25 pieces 400 x 100 x 100 mm prisms of each cementitious composite were cast – half in the common horizontal mould and other half into the new vertical mould. The trowel was used for laying of FRC into the moulds. The UHPFRC behavior was very smooth, sticky and honey consistent. This behavior was caused by the large amount of plasticizer to ensure the very low water/cement ratio and good workability. Therefore the UHPFRC was cast directly into the moulds because it´s honey consistence did not allow using of the trowel. All samples were filled into the half of the mould at first than vibrated for approx 15 sec. and filled up and again vibrated for 15 sec. Thirty cylinders of FRC (15 samples) and UHPFRC (15 samples) were cast to test the compressive strength of cement composite in each mixture set. The samples of cylinders and prisms were not specially treated after the de-moulding; they were just wrapped around by the plastic foil. Also three vertically and three horizontally cast prisms without fibers (NSC – normal strength concrete and UHPC – ultra high performance concrete) were carried out for both mixtures as reference samples. Fibers were replaced by aggregate in the same volume.

Table 1. The designs of the mixtures.

FRC 0,63%	(kg/m^3)	UHPFRC 1,5%	(kg/m^3)
CEM I 42,5R	370	CEM I 52,5R	800
-	-	Silica fume	200
-	-	Glass powder	200
Water	170	Water	176
Plasticizer	-	Plasticizer 1	24,8
-	3,5	Plasticizer 2	15,2
Aggregate 0-4 mm	1130	Aggregate ST01/06	336
Aggregate 4-8 mm	750	Aggregate ST03/08	680
Fibers – Dramix RC 80/30 (1000 MPa)	50	Fibers 13mm (2500 MPa)	120

Results of the Experimental Program

All samples were tested in approximately 30 days after casting so the typical compressive strength was developed. The experimental program consisted of investigation of prisms behavior during the three point bending test. The results of the compressive strength with the ultimate bending loads are stated in the Table 2. Compressive strength of referential samples was very similar to the FRC or UHPFRC respectively. It can be clearly seen in the Table 2 that the influence of vertical or horizontal casting plays significant role. The ultimate flexure capacity of the FRC was not affected by the way of mixture laying. There can also be observed that the load-displacement curves of vertically cast samples (V) descend much faster than the curves of horizontally (H) cast specimens (Fig. 1). The behavior of the UHPFRC was different because the capacity of the horizontally cast samples was approximately three times higher than capacity of vertically cast samples (Fig. 2). It was also observed on the fracture surfaces of the samples (UHPFRC) that the fracture surface of vertical cast samples was very smooth, without any protrusion and the fibers were laid in the circle parallel to the fracture surface. The fracture surface of the horizontal samples was coarser with protrusions and with fibers rising from the surface in the perpendicular direction to the fracture surface. The significant role can probably have the way of casting of the UHPFRC (Fig. 3) where fibers tend to get the direction perpendicular to the direction of mixture casting. This is probably caused by the honey-consistence of the UHPFRC where only relatively thin layer is pouring into the mould from the basket and then the mixture is spreading into the mould. Therefore there was not observed such a high difference between capacities of FRC because the trowel was used for casting. The fracture energy G_f according to Eq. 1 was approximately 4,5 times higher for the horizontally cast samples in comparison to the vertically casting for both types of mixture.

Table 2. Average values of ultimate loads, bending strengths and specific fracture energy of vertically (V) and horizontally (H) cast prisms.

	F_u [kN]		σ_f [MPa]		G_f [J/m^2]		F_u [kN]		σ_f [MPa]		G_f [J/m^2]	
	V	H	V	H	V	H	V	H	V	H	V	H
	FRC						**UHPFRC**					
Average	12,51	14,91	5,63	6,71	1478	6621	18,22	56,45	8,20	25,40	4145	18367
Std. Dev	0,96	2,54	0,43	1,14	680	1574	3,8	11,1	1,7	5,0	1515	5285
Ratio	1 : 1,19		1 : 1,19		1 : 4,48		1 : 3,1		1 : 3,1		1 : 4,4	
	NSC Reference						**UHPC Reference**					
Average	14,70	13,82	6,61	6,22	91	110	13,09	16,51	5,89	7,43	54,5	75,4
Std. Dev	0,53	0,07	0,24	0,03	9,7	10,8	0,33	1,91	0,15	0,86	15,0	9,8
Ratio	1 : 0,9		1 : 0,9		1 : 1,2		1 : 1,3		1 : 1,3		1 : 1,4	
f_c [MPa]	30,3						135,6					

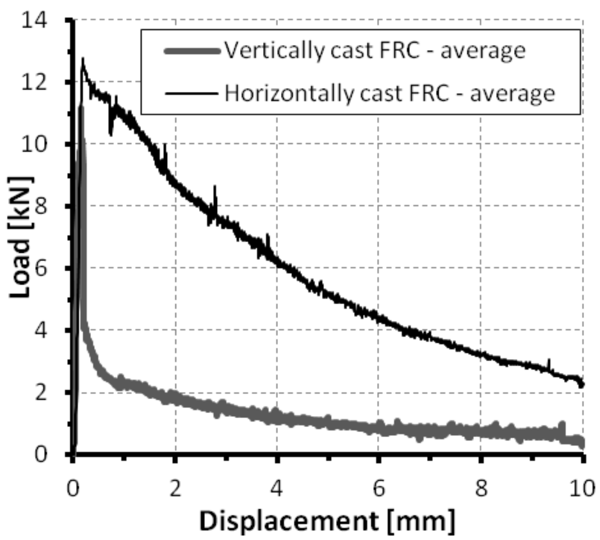

Fig. 1. The average load-displacement diagrams of FRC.

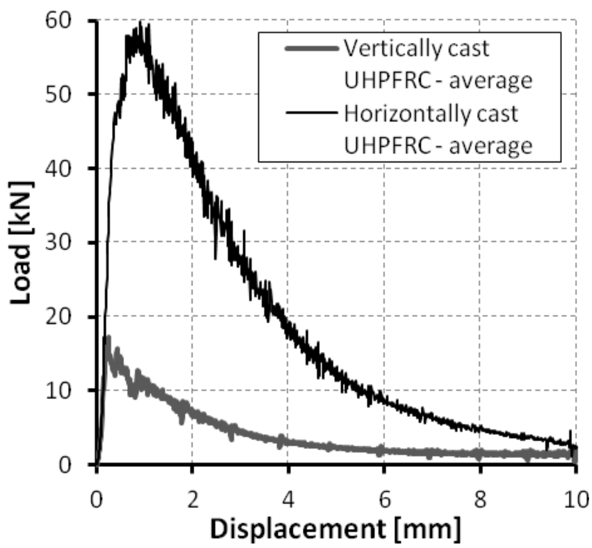

Fig. 2. The average load-displacement diagrams of UHPFRC.

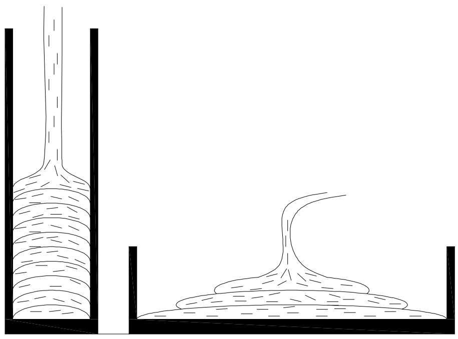

Fig. 3. The influence of the casting of UHPFRC on the fibers distribution.

Conclusions

The research presented in this paper was focused on the influence of casting direction during the three point bending test. Two fiber reinforced mixtures of cement composites were used for this purpose FRC and UHPFRC. The basic findings of this research can be summarized in next few points.

- The direction of the casting of the mixture has serious effect on the capacity (UHPFRC) and fracture energy of the tested specimens.
- The ultimate bending capacity of the vertically cast specimens of the UHPFRC was three times lower than the horizontally ones. On the other hand effect of lower bending capacity was not observed on the FRC samples.
- The further investigation confirmed that the vertically cast samples of both mixtures had approximately 4,5 times lower fracture energy then horizontally cast samples.
- The difference between vertically and horizontally cast samples can be explained by the tendency of the fibers to turn horizontally during the vibration of the mixture and the way of casting especially for the UHPFRC.

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