INFLUENCE OF FIBRE GEOMETRY ON THE FLEXURAL STRENGTH PERFORMANCE OF STEEL FIBRE REINFORCED CONCRETE (SFRC)

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Abstract

The flexural and equivalent flexural strength of seven different steel fibre types in SFRC with a dosage of 30 kg/m³ were tested with the four-point bending test. The steel fibres investigated are 3 end-hooked fibres with aspect-ratio/length of 80/60, 65/35 and 45/45, 2 crimped fibres with 50/50 and 60/60, one crimped end-flatted fibre with 60/60 and one straight end-capped fibre with 54/54. The end-hooked fibre 80/60 showed the best results. Also the other end-hooked fibres performed better than the crimped and end-capped fibre geometries. The differences in equivalent flexural strength behaviour of the investigated fibres are explained with a model, which allows the calculation of load-deflection curves based on fibre pull-out loads and number of fibres in the cracked concrete cross section. From these results it can be seen, that the number of fibres per kg fibre ($N_{f(w)}$), which is mainly influenced by fibre geometry, is an important factor for equivalent flexural strength performance of SFRC.

Keywords: steel fibre, steel fibre reinforced concrete, equivalent flexural strength, modelling, fibre geometry, aspect ratio, fibre distribution, number of fibres

Introduction

The collective fibre work in steel fibre reinforced concrete (SFRC) allows to carry stresses beyond concrete cracking. Therefore SFRC is used in structures subjected to cyclic flexural stresses such as industrial floors, roads, tunneling etc. [1, 3, 4, 5, 6, 7].

Nowadays, different types of steel fibres are offered. They vary in dimension and geometry [1, 5, 7]. Applied fibre dosages range from 20 to 60 kg/m^3 and for special cases even up to 100 kg/m^3 [1, 2].

In order to investigate the influence of fibre geometry on the equivalent flexural strength performance of SFRC, seven steel fibres with a constant dosage of 30 kg/m^3 were tested with the four point bending test.

The fibres investigated comprise end-hooked fibres DRAMIX RC 80/60 BN, DRAMIX RC 65/35 BN and KSF 45/1.0, crimped fibres TABIX1.0/60, TABIX1.0/ 50, crimped end-flatted fibre TABIX FE1.0/60 and straight end-capped fibre TWIN CONE 1.0/54 (figure 1).

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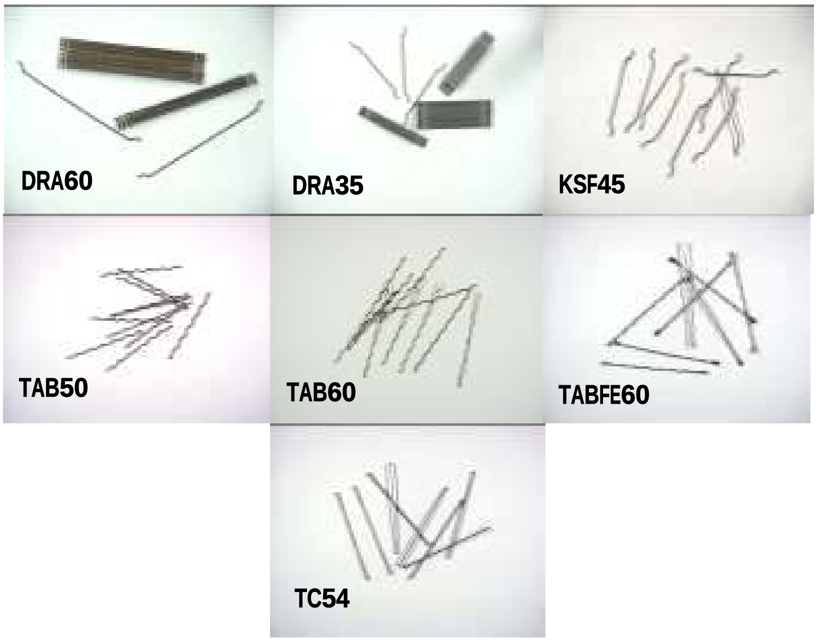


Fig. 1. investigated steel fibres

The dimensions of the fibres as well as sample code and aspect ratio are listed in Table 1.

Tab. 1 Fibre datas

fibre type	sample code	fibre geometry	length mm	diameter mm	aspect-ratio l/d
DRAMIX RC 80/60 BN	DRA60	end-hooked	60	0.75	80
DRAMIX RC 65/35 BN	DRA35	end-hooked	35	0.54	65
KSF 45/1.0	KSF45	end-hooked	45	1.0	45
TABIX 1.0/60	TAB60	crimped	60	1.0	60
TABIX 1.0/50	TAB50	crimped	50	1.0	50
TABIX FE 1.0/60	TABFE60	crimped-endflatted	60	1.0	60
TWINCONE 1.0/54	TC54	straight-endcapped	54	1.0	54

The mix design of the used concrete is shown in Table 2.

Tab. 2. Mix design of the concrete

components	dosage kg/m³
CEM II/A-M (S-L)	320
0/4 mm	778
4/8 mm	487
8/16 mm	683
water	160
w/b	0,5
Super plasticizer	1,5

Experimental

The flexural and equivalent flexural strength of the SFRC samples were tested and evaluated following the German guideline (*DBV, Deutscher Beton Verein*) [2] with the four-point bending test. The load-deflection curves of the samples were recorded with a deflection speed of 0,2 mm per minute up to a beam deflection of 3.5 mm. The beam span equals 600 mm and the load is introduced at 1/3 of span (figure 2).

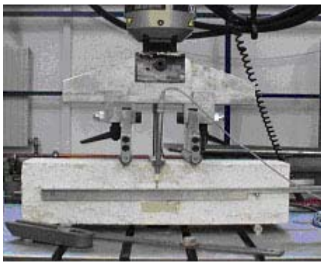


Fig. 2. four-point bending test

Each series consisted of three samples. From the load-deflection curves the flexural strength (f_{ct}) and the equivalent flexural strength for working capacity (*equBZ2*, area between first crack and deflection of approx. 0.65 mm) and for load bearing capacity (*equBZ3*, area between first crack and 3.15 mm) were determined.

Results and Discussions

The load deflection curves (average curves from three samples) for all investigated sample series as measured with the four point bending test are shown in figure 2. The curves are grouped according to the fibre geometries.

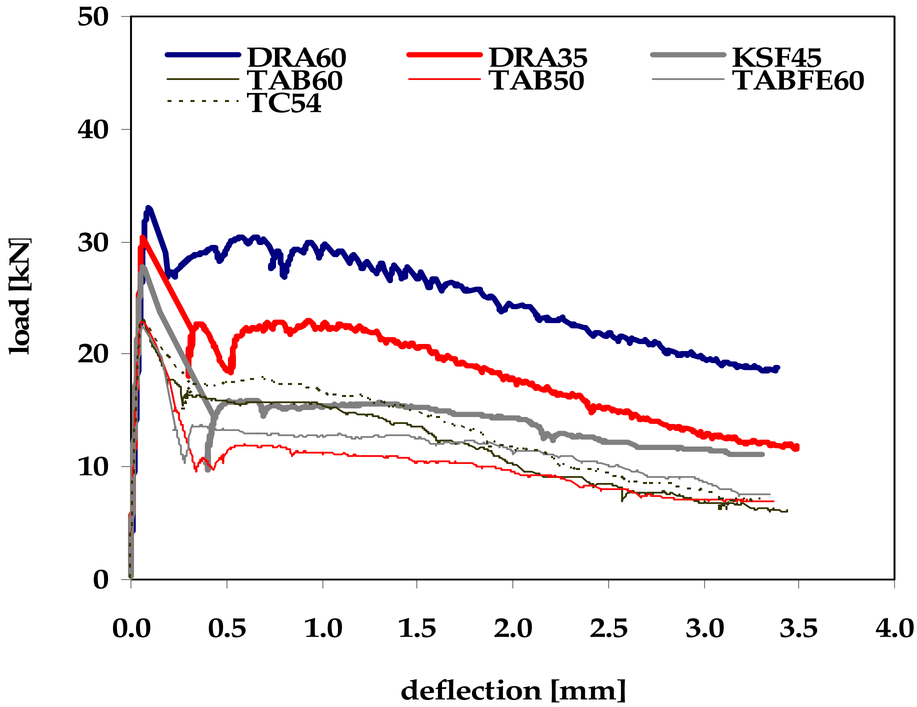


Fig. 2. Four point bending test and Load-deflection curves of SFRC samples

The flexural strength (f_{ct}) and equivalent flexural strength (*equBZ2* and *equBZ3*) determined from the load deflection curves are presented in figure 3.

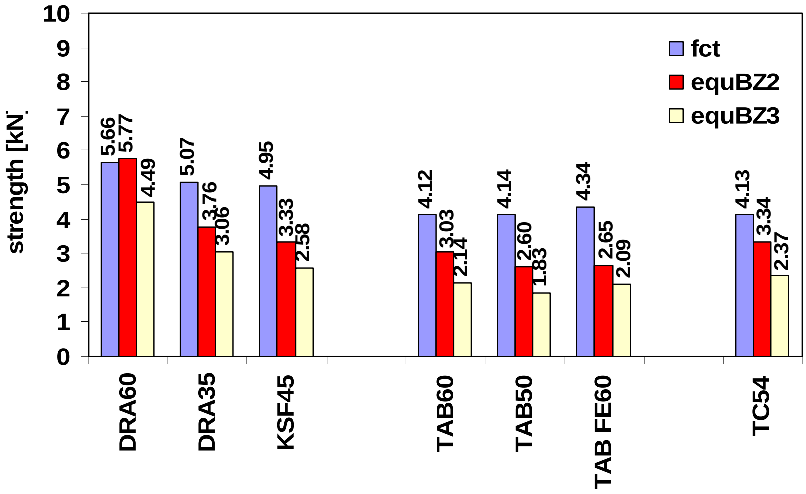


Fig. 3. f_{ct}, *equBZ2* and *equBZ3* of the series

The average 28 days compressive strengths of the investigated SFRC series are listed in Table 3.

Tab. 3. average compressive strength (f_c) of specimens at age of 28 days

	DRA60	**DRA35**	**KSF45**	**TAB60**	**TAB50**	**TABFE60**	**TC54**
f_c [N/mm²]	56.7	58.9	54.2	53.4	54.4	50.9	53.4

Flexural and equivalent flexural strength tendencies

The two end-hooked fibre series DRA60 and DRA35 show higher load-deflection curves compared to crimped and straight-endcapped fibres (Fig. 2). These fibres therefore also show the best results for flexural (f_{ct}) and equivalent flexural strength (*equBZ2* and *equBZ3*) as seen in Fig.3.

Evaluation of the performance of fibres with same geometry implies fibre-concrete bond, because the anchoring is more less the same. The fibre-concrete bond depends on the fibre surface (A_{sf}) and the number of fibres involved. In Tab. 4 the number of fibres per kg ($N_{f(w)}$), the amount of fibres in the crack according to the dosage of 30 kg/m³ (N_f, which has been determined from the investigated samples), the fibre surface (As_f) and total fibre surface (ΣA_{sf}), resulting from the amount of fibres present in the crack, are listed for the different fibre types.

Tab. 4. Characteristic datas for the fibres

Sample	fibre shape	$N_{f(w)}$	N_f	fibre surface, As_f [mm²]	Total fibre surface, ΣAs_f [mm²]
DRA60	end-hooked	4600	117	155.6	18205.2
DRA35	end-hooked	12000	165	69.6	11484.0
KSF45	end-hooked	3300	58	172.9	10028.2
TAB60	crimped	2660	53	190.9	10117.7
TAB50	crimped	3200	58	159.1	9227.8
TAB FE60	crimp-endflatted	2660	59	190.9	11263.1
TC54	straight-endcapped	2800	61	172.0	10492.0

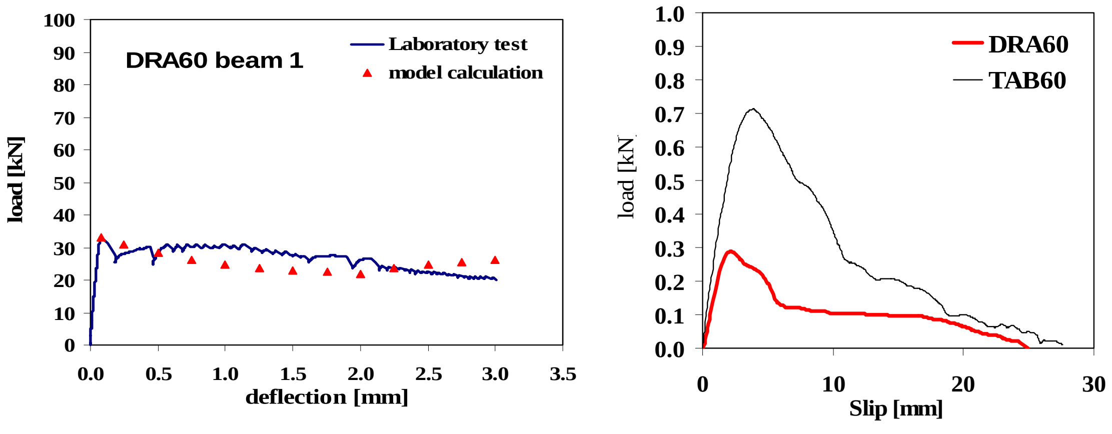
As can be seen DRA60 has the highest total fibre surface (ΣA_{sf}) among the end-hooked fibres. This larger surface and therefore larger fibre-concrete bond might be responsible for the better equivalent flexural performance compared to the other two end-hooked fibres. The anchoring is more or less the same for the end-hooked fibres. The crimped fibres have very similar total fibre surfaces and therefore perform also similar in the four-point bending test.

In Tab. 4. it can be seen that fibre geometry determines the amount of fibres per kg ($N_{f(w)}$) and consequently the amount of fibres present in the crack. Therefore fibre geometry contributes to the SFRC strength.

Model calculation based on fibre pull-out measurements

The load-deflection curve of SFRC from the four point bending test can be reconstructed with a model presented in [1]. This model assumes that the resistance to further deflection after the first crack consists of the total fibre pull-out force and the residual uncracked concrete cross section (the cross section is linearily reduced up to a deflection of 2 mm). The total pull-out force is calculated by multiplying the single fibre pull-out load at certain slip with the number of fibres (N_f) in the crack.

In Fig. 5(a) a model calculation of the load-deflection curve for a DRA60 sample based on the measured fibre pull-out curve (fig. 5(b)) and the characteristic data for this fibre (N_f) is shown. The agreement between measured and calculated curve is very satisfactory and is able to predict equivalent flexural strength behaviour of this SFRC. Fig. 5(b) compares the pull-out curves for the end-hooked fibre DRA60 and the crimped fibre TAB60. Allthough the fibre TAB60 shows higher pull-out force, the performance of this fibre in SFRC is less than for DRA60 at same dosage.



(a) (b)

Fig 5. (a) Measured and calculated load-deflection curve for SFRC beam with DRA60
(b) Single fibre pull-out load for end-hooked DRA60 and crimped TAB60

The different fibre geometry – in terms of shape and dimension - causes the variation of fibre amounts per mass unit ($N_{f(w)}$) and correlates strongly with the number of fibres (N_f) in the crack. The above model calculation demonstrates that the amount of fibres in the crack can compensate for lower pull-out forces and leading to better SFRC performance.

Fibre length and diameter, expressed as aspect ratio, is correlated to pull-out behaviour for fibres of same geometry. However, for different fibre geometries this correlation is not any more valid, as can be seen from the comparison of the equivalent flexural strength behaviour of SFRC with fibres DRA35, TAB60 and TABFE60.

Conclusions

From this work it is concluded, that

(a) the differences of steel fibre geometry – shape and size - cause variation in bridging and pull-out mechanisms, fibre-concrete bond and amount of fibres per unit mass ($N_{f(w)}$). Consequently, fibre geometry influences the flexural performance of SFRC.

(b) The flexural performance of SFRC will be optimum if fibre geometry can maximize fibre resistance with high number of fibres per unit mass ($N_{f(w)}$) and with anchoring and surface bond strengths below fibre´s tensile strength..

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