SELF-COMPACTING FIBRE REINFORCED CONCRETE APPLIED IN THIN PLATES

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ABSTRACT

Floor panels produced with traditionally vibrated concrete are relatively thick due to the need to reinforce concrete and consequently, heavy. Without the need to place rebars in panels and by applying self-compacting fibre reinforced concrete (SCFRC) the production process becomes more efficient. Fibres improve the performance of concrete by counteracting the crack-growth during loading. Their efficiency also depends on how they are distributed and oriented in a cementitious matrix.

This paper describes a study on the application of thin plates with self-compacting concrete with and without fibres for floors; other materials like steel or wood often are applied for this application. Six concrete panels (dimensions: 600·600·15 mm^3) were tested in this study; no rebars were placed in the elements. Self-compacting concrete was applied and the dosage of steel fibres was varied (0; 0,99 and 1,97 Vol.-%). The plates were tested by point-loading; the failure pattern depended on the fibre dosage.

Keywords: self-compacting concrete; thin plates; fibres; fibre orientation

INTRODUCTION

Self-compacting concrete (SCC) is one of the most remarkable developments of concrete technology of the past decades. An application with SCC combined with fibres has the following potential benefits: freedom of shape, better structural performance, improvement of aesthetical appearance, very slender structures (i.e.

sheet piles [1] or facade elements [2]) can be designed, reduced construction heights and elimination of supports, new structural and design possibilities [3], decrease of transport, storage and placement costs, improved durability and/or decreased maintenance costs. Without the need to vibrate concrete the working circumstances are improved and concrete is more homogenous, which enhances the quality and the performance. Compared to other building materials, concrete is inflammable and can be composed to resist extreme fire-loadings. In this paper, the application of SCFRC for the application of plates in a double-floor system is discussed. Reasons to apply SCFRC for thin plates are an improved production efficiency, a thinner and lighter structure (plate, support and foundation) and high concentrated forces can be transferred with a high compressive strength material. The performance of the plates was compared to categories defined by EN 12825 [4], which depend on the maximum design load, the chosen safety factor and the allowable deformation of the plates. In case of static loading of floor plates, EN 12825 defines six categories dependent on the load capacity (Table 1). Static loading and when necessary, other load cases have to be taken into account for the design (i.e. dynamic loading, fire resistance, noise reduction, electrical conductivity and/or isolation capacity). In this feasibility-study, only quasi-static loading is considered.

Table 1. Element class depending on the load capacity

Class	Max. load [KN]
1	>4
2	>6
3	>8
4	>9
5	>10
6	>12

The maximum design load also depends on the safety factor (EN 12825: 2,0 or 3,0). An additional requirement for plates is the maximum vertical deflection. Three deflection categories are defined (Category A being the class with the lowest allowed deflection of 2,5 mm; Class B: 3,0 mm/Class C: 4,0 mm). After a loading period of 30 minutes at the maximum load and a 5 minutes period of de-loading, the maximum allowed vertical deflection is 0,5 mm. A thin plate supported on four points at its edges can fail at different locations when loaded by a concentrated force. The dimensioning of the supports is critical for the design of load-bearing floor structures. According to EN 12825, the plates have to be loaded by a testing machine with a steel prism having a relatively small contact area ($25 \cdot 25$ mm^2). Failure can initiate in the middle of the weakest plate-side, in the middle of the plate, in one of the diagonals or at every other point of a material that has weak spots.

EXPERIMENTAL SET-UP

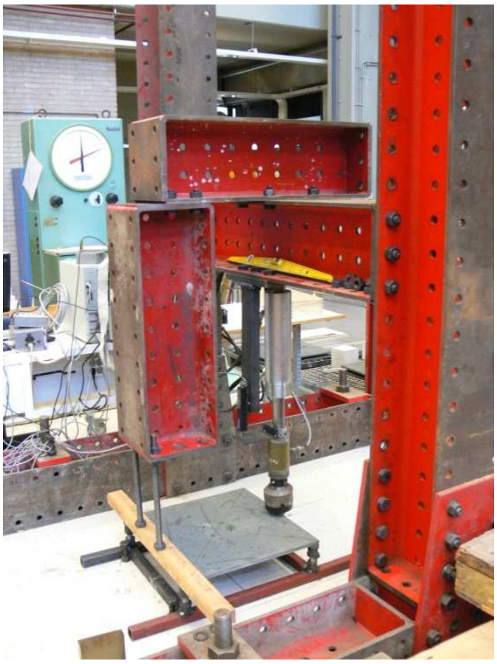
The thickness of the plates in this study was fixed to 15 mm. With a plate thickness of 15 mm and rebars having a diameter of 4-5 mm only a thin concrete cover (+/- 5 mm) can be realized. A durable but more expensive option would be to apply coated or stainless steel rebars. Self-compacting concrete with and without steel fibres was applied; the fibres contribute to a high flexural capacity without the need to place rebars. Six thin plates (dimensions: 600·600·15 mm^3) were produced and were tested in the Stevin-Laboratory of Delft University of Technology. The dosage of steel fibres (straight, L_f=13 mm, d_f=0,20 mm) was varied (0; 0,99 and 1,97 Vol.-%); two plates were produced with each mixture. Table 2 shows the mixture composition of Mixtures 1-3. Self-compacting concrete (volume: 60 litres) was prepared with a forced-pan type mixer (producer: Zyklos, maximum mixing capacity: 120 litres).

Table 2. Mixture composition of self-compacting concrete with and without steel fibres for thin plates

Component	**Producer**	**Mix** [kg/m³]	**Mix2** [kg/m³]	**Mix 3** [kg/m³]
CEM I 52.5 R	ENCI	358	358	358
CEM III/A 52.5	ENCI	555	555	555
Silica fume	BASF	61	61	61
Sand (0.125-0.5)	river, round	574	562	549
Sand (0.5-1.0)	river, round	574	562	549
Steel fibres (OL13/0.20)	Dramix	0	77,5	155
Superplasticizer, Glenium 51	BASF	21,0	21,0	21,0
Total water (incl. superplasticizer)		226	226	226
water/cement-ratio		0.25	0.25	0.25

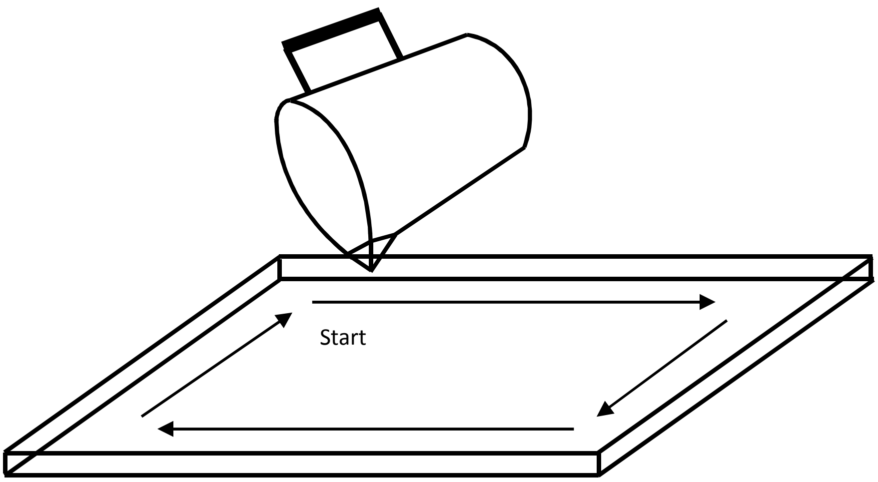
Figure 1 shows the set-up of the testing machine. A welded frame with four adjustable columns (area of plate support: 30·30 mm^2) was arranged in a quadratic layout (600·600 mm^2). The frame was sufficiently stiff in order to prevent deformations and the displacement of the supports. The top of each column consisted of a steel plate (40·40·15 mm^3) welded on a M24-bolt in order to be able to adjust the height of the supports. The steel columns supported the concrete plates on four edges. The contact area of the loading head of the testing machine and the plates had the dimensions of 25·25 mm^2. The tests were carried out load-controlled. According to EN 12825, the load-controlled tests on plates have to be carried out at a rate of 120 N/s +/- 10 % until failure of any part of the plate is observed. In this feasibility-study, the load was manually increased in steps with a pneumatic pump; the load and the deflection of the plate (at the loading head) was continuously recorded during testing.

Figure 1. The testing machine with a thin plate placed on four supports; the loading head is placed between two supports at the edge of the plate



The casting method was chosen to optimize the performance of the fibres by aligning them in the direction of principal stresses. The most critical loading point of the plate was assumed to be at the edge in the middle of the span between the supports; fibres aligned parallel to the walls of the formwork improve the load-bearing capacity in this loading case. Self-levelling concrete was filled in a bucket and the formwork was filled according to the procedure indicated by Figure 2. The fibres oriented due to the flow through the bucket and due to the free flow in the mould parallel to the walls of the formwork. The slump flow was 799 mm (without fibres), 752 mm (V_f=77,5 kg/m^3) and 688 mm (V_f=155 kg/m^3).

Figure 2. Filling procedure for thin plates



RESULTS AND DISCUSSION

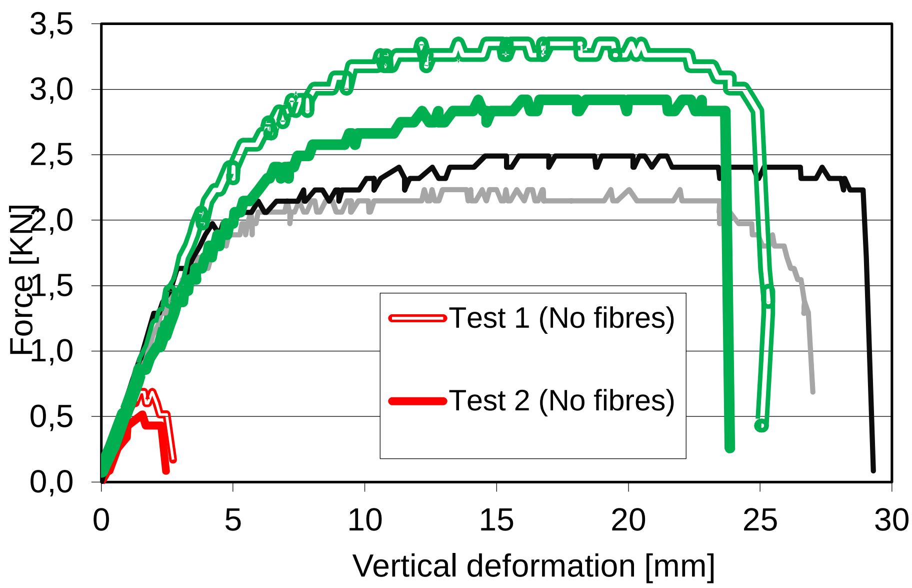
The plates were tested 56 days after casting. Table 3 shows the results of compression and splitting tensile tests executed at different concrete ages; the results are single tests obtained with cubes of 100 mm.

Table 3. Compressive and splitting tensile strengths at different concrete ages and with different fibre contents

Fibre dosage Concrete age [days]	0 [kg/m³]	77,5 [kg/m³]	155 [kg/m³]
Compressive strength	*[MPa]*	*[MPa]*	*[MPa]*
14 days	124,4	129,1	140,1
28 days	-	-	150,3
56 days	148,1	144,7	164,2
Splitting tensile strength	*[MPa]*	*[MPa]*	*[MPa]*
56 days	12,6	16,4	17,4

The increase in compressive strength due to the addition of 155 kg/m^3 steel fibres 56 days after casting was 16,1 MPa (10,9 %) compared to the reference mixture without fibres (14 days: 15,7 MPa). At the highest fibre dosage the splitting tensile strength 56 days after casting was 17,4 MPa, which is a strength increase of 38 % compared to the reference mixture without fibres. Figure 3 presents the load-deflection results of the six plates.

Figure 3. Load-deflection diagram: concentrated loading of thin plates



The fibres (Tests 3-6) significantly increased the maximum load and ductility of the plates compared to the reference plates (Plates 1-2). The load-increase (average of two results) was 393% relative to the maximum load obtained with the reference plates (without fibres) with 50% of the maximum fibre dosage and 507% with 100% of the maximum fibre dosage, respectively. The improvement of the maximum flexural strength with 77,5 kg/m^3 extra fibres was only 29% (fibre content 1,97 Vol.-% compared to 0,99 Vol.-%). Table 4 summarises results concerning the maximum load and the vertical deformation at the maximum flexural load.

Table 4. Maximum load and vertical deformation at the maximum load

Plate Nr.	Fibre dosage [Vol.-%]	Force [kN]	Average max. load [kN]	Def. at max. load [mm]
1	0	0,69	0,60	1,46
2	0	0,52		1,55
3	0,99	2,23	2,36	12,26
4	0,99	2,49		14,57
5	1,97	2,83	3,05	14,31
6	1,97	3,26		12,14

The highest load was obtained in Test Nr. 6 (3,26 KN). The lowest strength class according to EN 12825 (Table 1: Class 1) requires a minimum load of 4 KN, which also includes a reduction of the characteristic experimental strength by a safety factor (2,0 or 3,0 dependent on the application). Furthermore, the maximum deflection at the maximum load is limited. The maximum deflection is a critical design parameter for thin plates. The flexural behaviour of Plates 5-6 is almost linear up to a vertical deflection of 4 mm. At a deflection of 4 mm (Class C), the experimental load of Plate 6 was 2,03 KN (only 50,8 % of the strength required for Class 1, Table 1) without considering statistical variation and safety factors (Table 5). In spite of an important contribution of the steel fibres to the flexural performance, the results indicate that thin plates require a higher strength and a stiffer flexural behaviour in order to fulfil the criteria according to EN 12825.

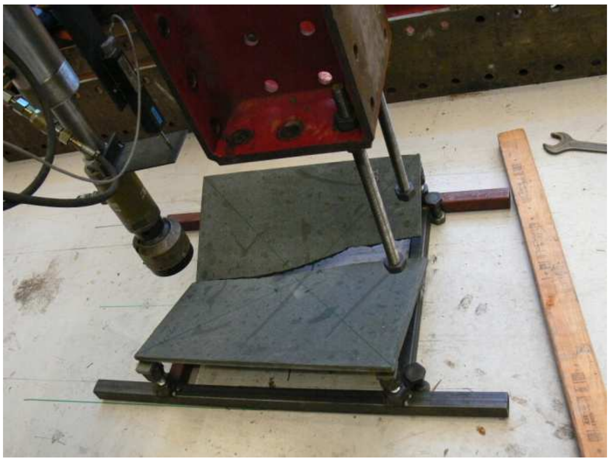
Table 5. Load of the 6 plates at a vertical deformation of 2,5, 3 and 4 mm, respectively

Deflection class Load [KN]	A 2,5 mm	B 3 mm	C 4 mm
Plate 1	0,49	-	-
Plate 2	-	-	-
Plate 3	1,29	1,48	1,72
Plate 4	1,42	1,63	1,90
Plate 5	1,06	1,29	1,63
Plate 6	1,25	1,52	2,03

The thickness of the plates has to be increased in order to meet the requirements on stiffness. The strength level can be increased by adding additional fibres and/or rebars.

Coated or stainless steel rebars could be applied in case of insufficient concrete cover and/or too high production tolerances. Plates 1-2 failed brittle in bending with a single crack running through the middle of the plate between the supports (Figure 4: Plate 1). The maximum load of Plate 2 was only 0,52 KN.

Figure 4. Failure pattern of Plate 1 after the execution of the test



Plates 3-6 locally failed in the vicinity of the loading head (Figure 5: Plate 3 (V_f=77,5 kg/m^3); Figure 6: Plate 6 V_f=155 kg/m^3)). In each case, a small part of the plate was pushed down by the loading head.

Figure 5. Horizontal view on Plate 3 after the execution of the test

Figure 6. Horizontal view on Plate 6 after the execution of the test

The failure patterns of Plates 4-5 were similar with the failure pattern shown by Figure 5 (Plate 3). The failure pattern of Plate 6 differed from Tests 3-5: an additional crack appeared in the pulled-out concrete part of Plate 6 below the loading prism. The flexural strength of Plate 6 was the highest of all plates. Relatively more fibres crossed the cracks around the loading position (Plate 6 compared to Plate 5); the additional crack surface in Plate 6 contributed to the load-bearing capacity. The deflection at the maximum load is the sum of the elastic deformation of the plate and a local deformation (by opening of cracks) close to the loading head.

CONCLUSIONS

This paper describes the testing of thin plates produced with self-compacting concrete with and without fibres for the application 'plates in a double-floor system'. Based on the experimental study the following conclusions can be drawn:

- The flexural performance of thin plates was significantly enhanced due to the addition of steel fibres. The maximum load increased by 393% (V_f=77,5 kg/m^3) compared to plates that contained no fibres. By doubling the fibre dosage the maximum flexural strength was increased by a moderate 29% relative to plates containing half the fibre dosage.
- The failure pattern depended on the content and the distribution of the fibres.
- In order to be applied as floor panels according to EN 12825 the flexural strength and flexural stiffness of the panels have to be increased. Increasing the thickness of the plates (alternatively: ribs could be considered) is necessary to fulfil the criterion on the maximum deflection at the maximum load.

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