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Effect of Steel Fibre Content on the Properties of Concrete

Authors: E Kearsley[1] and W Elsaigh[2]

[1]Associate Professor in Civil Engineering, University of Pretoria
[2] PhD Student, University of Pretoria

ABSTRACT: Steel fibre reinforced concrete (SFRC) is defined as concrete containing randomly oriented, discontinuous, discrete steel fibres. In this study, an experimental investigation was carried out to measure the effect of steel fibre dosage on workability, compressive strength, modulus of rupture and toughness characteristics.

SFRC, containing 10, 15, 20, 25 and 30 kg/m^3 of hook-ended steel fibres, was compared to its parent plain concrete. It was found that the steel fibre dosage has an influence ranging between little and significant on these properties. It significantly reduces the workability at higher dosages while it has a minimal effect at low dosages; marginally increases compressive strength; significantly increases the modulus of rupture; marginally increases the flexural strength and significantly increases the toughness.

Journal Contact Details:
PO Box 75364
Lynnwood Ridge
Pretoria, 0040
South Africa
+27 12 348 5305

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TECHNICAL PAPER - EFFECT OF STEEL FIBRE CONTENT

PROPERTIES OF FOAMED CONCRETE AS INFLUENCED BY AIR -VOID PARAMETERS

By: W. Elsaigh and E. Kearsley
Department of Civil Engineering, University of Pretoria.

Walied Elsaigh graduated in Civil Engineering from Khartoum University, Sudan in 1996 and he obtained his honours (1999) and master (2001) degrees in Transportation Engineering from the University of Pretoria, South Africa. He worked on many projects as a consulting Engineer. He is currently enrolled as full time Ph.D. student at the University of Pretoria.

Elsabe Kearsley graduated from the University of Pretoria with a BEng (Civil) degree in 1984. She holds a PhD from the University of Leeds (UK). After working in the design office and on construction sites for consultants in both South Africa and the UK, she joined the staff of the University of Pretoria in 1990 where she is currently employed as Associate Professor in Civil Engineering. During the past ten years she has conducted various research projects regarding concrete materials.

ABSTRACT

Steel Fibre Reinforced Concrete (SFRC) is defined as concrete containing randomly oriented discontinuous discrete steel fibres. In this study, an experimental investigation was carried out to measure the effect of steel fibre dosage on workability, compressive strength, modulus of rupture and toughness characteristics. SFRC, containing 10,15, 20, 25 and 30 kg/m^3 of hook-ended steel fibres, was compared to its parent plain concrete. It was found that the steel fibre dosage has an influence ranging between little and significant on these properties. It significantly reduces the workability at higher dosages while it has a minimal effect at low dosages, marginally increases compressive strength, significantly increases the modulus of rupture, marginally increases the flexural strength and significantly increases the toughness.

1. INTRODUCTION

Historically, many types of fibres have been used to reinforce brittle materials. Straw was used to reinforce sun-baked bricks; horse-hair was used to reinforce plaster and more recently, asbestos fibres were been used to reinforce Portland cement[(1)]. In the past several years, considerable interest has been generated in the use of concrete containing discrete, randomly oriented steel fibres (SFRC) for various structural applications, notably, concrete pavements.

Dispersion of steel fibres was found to improve the concrete mechanical characteristics. This improvement can be attributed to the crack controlling mechanism provided by the steel fibres. The effect of stress intensity in the vicinity of micro-cracks reduced by one or both of the following suggested mechanisms[(2)]:

Steel fibres bridge the crack and transmit some of the load across the crack.

Steel fibres near the crack tip resist higher loads because of their higher modulus of elasticity compared to the surrounding concrete.

Preliminary trial mixes indicated that the addition of steel fibres to a properly designed concrete mix reduced the slump due to additional paste required to coat the steel fibres[(3)].

As far as the effect of steel fibres on compressive strength is concerned, conflicting results were obtained. Experimental work conducted in India, using straight steel fibre with Length/Diameter ratio (aspect ratio) of 46/0.91 and fibre content ranges between 0 and 230 kg/m^3 (0 and 3% by volume), found that a significant increase in compressive strength is achieved (about 40% increase when using 230 kg/m^3 fibre content)[(4)]. On the other hand, tests in Australia showed that, the addition of steel fibres to a concrete matrix might produce marginal gains in compressive strength at constant water cement ratio. At steel fibre concentrations of 50 to 90 kg/m^3 (0.6 to 1.2 % by volume) the increase in compressive strength is not usually statistically discernible(5).

The low flexural strength of plain concrete could possibly be over-come by the addition of steel fibres. A review of the literature on SFRC indicates that in general, the addition of short, randomly-oriented steel fibres increases the flexural strength of plain concrete by about 1.5 to 3.0 times, taking into account type and content of the steel fibres[6, 7, 8].

Toughness as defined by the ACI committee 544 is the total energy absorbed prior the complete separation of the specimen[1]. It can be calculated as the area under the load-deflection curve plotted for beam specimen used in a flexure test. Although, it was established that the steel fibres significantly improve concrete toughness and it is widely agreed that toughness can be used as a measure of the energy absorption of the material, there is a doubt about the way that SFRC toughness should be measured and used.

Two methods to interpret and calculate the toughness of SFRC are widely used. The ASTM C1018-97 method in which the energy absorbed up to a certain specified deflection is normalized by the energy up to a point of first cracking[9]. The Japanese Institute of Concrete standards (JSEC-SF4) interprets the toughness in absolute terms, as the energy required to deflect the beam specimen to a mid point deflection of 1/300 of its span[10, 11]. To quantify the flexural strength of SFRC, the following terms are important:

- Flexural strengt f_{ct} hand modulus of rupture: recognized as the strength relevant to the maximum load on the load-deflection curve.
- Equivalent flexural strength $f_{ct,\,1.5}$: The stress capacity derived at a point of specific mean load corresponding to a certain deflection (termed as the equivalent flexural ratio). It describes the additional after cracking strength associated with SFRC.
- Equivalent strength ratio $R_{e,\,1.5}$: is the ratio between the equivalent flexural strength and the flexural strength.

The published results on this subject were mostly for SFRC containing either straight steel fibres or a relatively high amount of steel fibre. In recent years, optimisation of the shape and strength of steel fibres has made possible to use lower steel fibre dosages. The objective of this paper is to determine the influence of hook-ended steel fibre with relatively low content (ranges between 0 and 30 kg/m³) on the properties of concrete. The properties measured include workability, compressive strength, and modulus of rupture (*MOR*) as well as post-cracking ductility characteristics or toughness.

EXPERIMENTAL PROGRAM

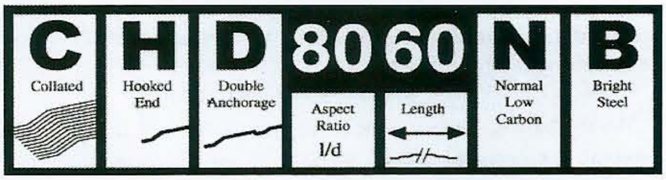
Material Used

The concrete mixtures used in this investigation are based on the mixture shown in table 1. Six mixtures having steel fibres dosages of 0, 10, 15, 20, 25, 30 kg/m³ were cast. Steel fibres (CHD 80/60 NB) used in this investigation were hook-ended wires with an aspect ratio of 80, length of 60 mm and a tensile strength of 1100 MPa as indicated in figure 1. Fly ash was used as cement replacement to improve the workability of the mixture and to increase the mixture paste content.

Table 1: Mix Composition

Material	Mass (kg/m³)
Cement	282
Water	194
Pozzfil	78
19 mm Stone	883
13 mm Stone	222
Crusher Sand	662
Filler Sand	72

Figure 1: Description of Tested Steel Fibres[12]



Procedure

The effect of steel fibre dosage on workability, compressive strength, *MOR*, flexural strength (f_{ct}), and equivalent flexural ratio ($R_{e,\,1.5}$) was studied.

The workability of six mixtures containing steel fibre contents between 0 and 30 kg/m³ were compared using a standard slump test. The standard apparatus was used and the standard procedure was followed as prescribed by the SABS Standard Method 862:1994[13].

Compressive strength tests were carried out after 7 and 28 days on standard cubes (150x150x150 mm). Three specimens (for each mix) were tested after 7 days and three other specimens tested after 28 days. The procedure prescribed by SABS Standard Method 863:1994[14] was followed.

Standard *MOR* tests were carried out according to the DIN Standard Method1048: 1991[15] on three specimens for every mixture. The failure load is determined andwas calculated on the basis of ordinary elastic theory as follows:

$$MOR = \frac{P_{max} L}{bh^2} \quad \text{(Equation 1)}$$

Where is the maximum load, is the tested span and and are the width and depth of the beam respectively.

TECHNICAL PAPER - EFFECT OF STEEL FIBRE CONTENT (cont.)

Three standard beam specimens (150x150x750 mm) for each mix were tested after 28 days to determine their first crack flexural strength and toughness characteristics.

A closed-loop Material Testing System (MTS) was used in displacement control to apply the load, measure the applied load and record deflection. Displacement was applied at a rate of 0.02mm/sec and 10 readings per second were recorded. The test set-up is shown in figure 2. Mid-span deflection was measured by using two Linear Variable Displacement Transducer (LVDTs).

The load was applied by using two bearing rollers (one of them a swivelling roller) 150 mm apart with their centre line adjusted 75 mm from centre of the beam. The beam supports were 450 mm apart and bolted to the MTS testing bed.

The Japanese standard method (JSCE-SF4)[10] was used to calculate the equivalent strength and equivalent strength ratio. The following steps were followed:

- The area under the load-deflection curve up to mid-span deflection of 1.5 mm (tested span is 450 mm) was calculated.
- The Equivalent load ($P_{e,1.5}$) is then calculated by dividing the area under the load-deflection curve up to 1.5 mm deflection by the deflection of 1.5 mm.
- The equivalent strength ($f_{e,1.5}$) and equivalent flexural ratio ($R_{e,1.5}$) were calculated using equation (2) and equation (3) as follows:

$$f_{e,1.5} = \frac{P_{e,1.5}\, L}{bh^2} \quad \text{(Equation 2)}$$

$$R_{e,1.5} = \frac{f_{e,1.5}}{f_{ct}} \quad \text{(Equation 3)}$$

The flexural strength (f_{ct}) is calculated in similar manner using equation 2 by substituting the maximum load obtained (under displacement control test) instead of the equivalent load $P_{e,1.5}$

RESULTS

Table 2 shows the average results of the slump test, compressive strength, and third-point loading tests. The equivalent flexural ratio at a deflection of 1.5 mm is also calculated using the JSCE-SF4. It is worthwhile to mention that, the is the maximum stress obtained from a test conducted in a load control and the flexural strength is the stress obtained from a test with a different set-up in deflection control, these two values can therefore not be compared.

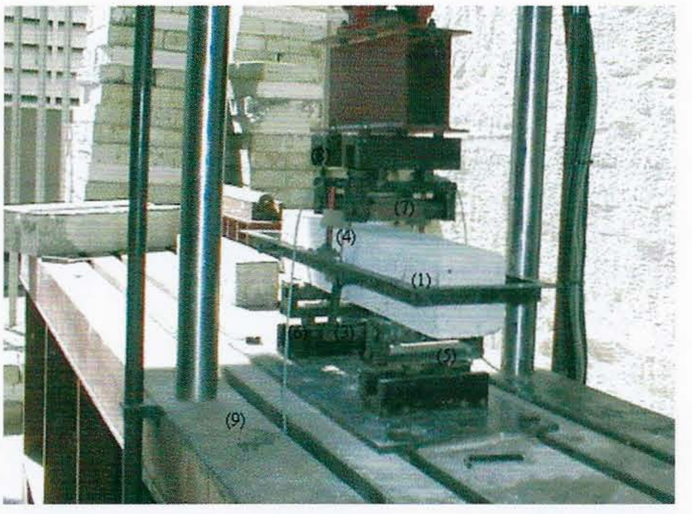


Figure 2: Test Set-up for the Third-point Loading Test

(1) Steel rig,
(2) MTS loading arm,
(3) Griping clamp,
(4) LVDTs clamp,
(5) Swivelling support,
(6) Fixed support,
(7) Fixed loading cylinder,
(8) Swivelling loading cylinder and
(9) MTS testing bed.

An example of typical load-deflection curves can be seen in figure 3. Only load-deflection curves for plain concrete and SFRC containing 15 and 30 kg/m3 are presented. It can be seen that plain concrete has failed

Table 2: Effect of Steel Fibre Dosage on Properties of Concrete

Property	**Steel Fibres Dosage (kg/m³)**					
Property	0	10	15	20	25	30
Slump (mm)	135	135	145	100	80	90
Cube 7 days (MPa)	29.4	35.9	31.4	31.1	32	32.1
Cube 28days (MPa)	43.8	48.5	47.2	44.3	44.7	46.4
Modulus of Rupture (MOR) **(MPa)**	4.1	4.9	4.8	5	5.3	5
Flexural Strength (f_{ct}) **(MPa)**	5	5.2	5.2	5.4	5.3	5.5
Equivalent Strength ($f_{e,1.5}$) **(MPa)**	0	2.0	1.9	2.4	2.7	3.3
Equivalent Flexural Ratio ($R_{e,1.5}$)	0	38.5	36.5	44.4	55.1	67.3

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in a brittle manner while SFRC has behaved in a more ductile manner. Increasing the steel fibre dosage has caused the beam to absorb greater energy at post-cracking stage. This ductile behaviour of SFRC can be explained by the cracking mechanisms.

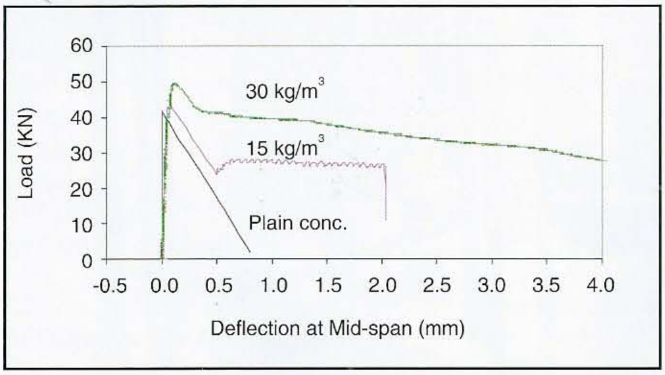

Figure 3: Typical Load-deflection curves

DISCUSSION

Workability

Figure 4 shows the effect of the steel fibres dosage on workability of the concrete mixtures. The dotted line shows the general trend for the effect of steel fibre content on workability. It shows that addition of steel fibre has a minimal effect on workability for low dosage while it has significant effect for higher dosages.

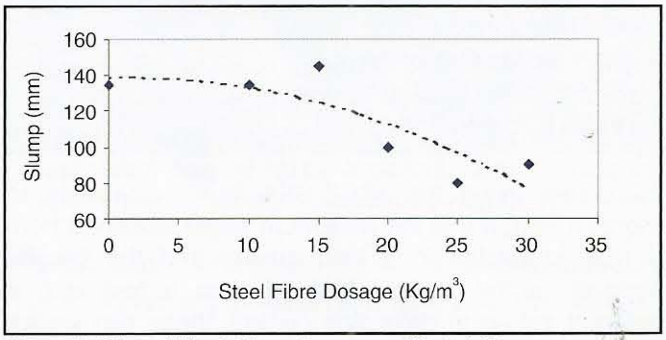

Figure 4: Effect of Steel Fibres Dosage on Workability

Compressive Strength

Figure 5 show that the steel fibre has a minimal effect on the compressive strength of the concrete mixture. An increase of minimum 1% to a maximum of 10% for different dosages is obtained. It should also be noticed that the 7 days and the 28 days curves are following approximately the same trend, which in turn means that some sort of consistency is normally associated with the strength growth characteristics of the SFRC.

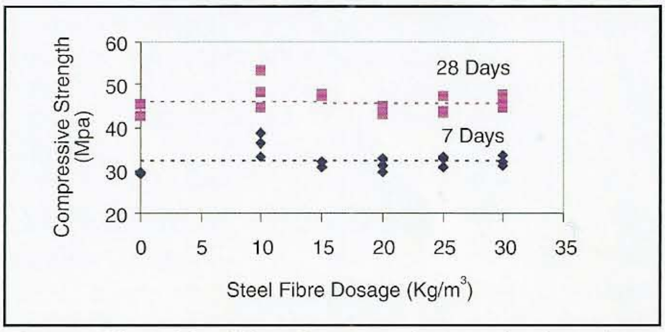

Figure 5: Effect of Steel Fibres Dosage on Compressive Strength

These results correlate well with the test carried out at the CSIR (South Africa). It was found that the addition of steel fibres with various dosages may increases the compressive strength slightly (approximately 10%) and the most increase occurred at low steel fibre contents (up to 20 kg/m³). In addition to that, a specific limit does exist beyond which an excessive increase of fibre dosage will not affect or have a minimal effect on the compressive strength[16].

Modulus of Rupture (*MOR*)

Figure 6 shows the effect of the steel fibre dosage on. It shows that about 29% increase is found for concrete containing steel fibres of 25kg/m³. The orientation of the individual steel fibres might profoundly affect the measured strength. The strength reading at steel fibre dosage 30 kg/m³ is slightly less than the strength at lower steel fibre dosage. Considering normal deviations in testing concrete, these tests are not sufficiently conclusive and a statistical analysis should predict a slight upward trend.

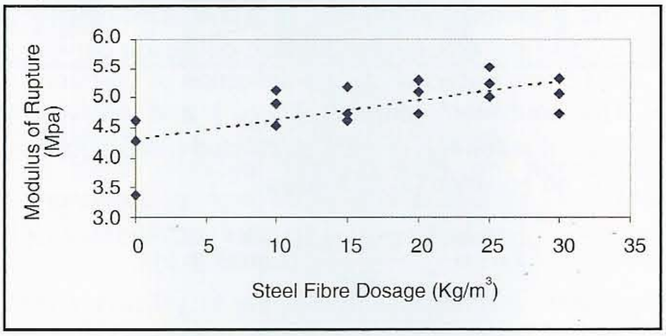

Figure 6: Effect of Steel Fibres Dosage on Modulus of Rupture

Toughness

Figure 7 shows the effect of steel fibre dosage on flexural strength. The highest increase found was 10% with dosage 30 kg/m3. The general trend shows that steel fibre dosage results in a marginal increase on the 28 days flexural strength.

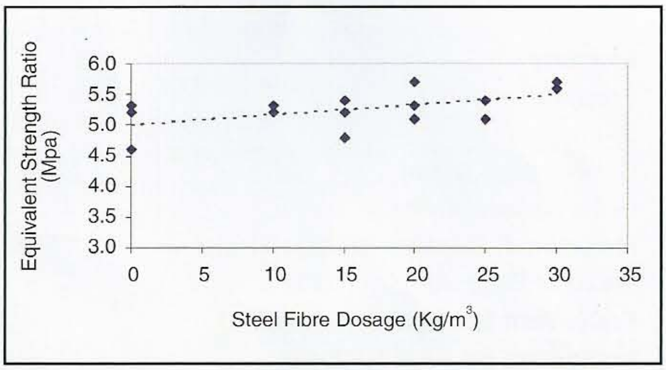

Figure 7: Effect of Steel Fibres Dosage on Flexural strength

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Figure 8 shows the strength equivalent ratioas a function of steel fibre dosage. From the graph it is noticeable that the addition of the steel fibres to concrete increases the toughness of the concrete by more than 67% at steel fibre contents of 30 kg/m³. The general trend shows that a significant increase in toughness is gained by adding even low steel fibre dosages.

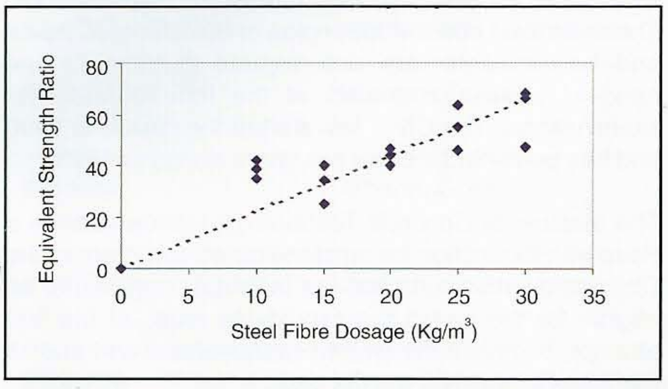

Figure 8: Effect of Steel Fibres Dosage on Toughness

CONCLUSIONS

The steel fibre dosage was found to influence the workability, compressive strength, and toughness characteristics as follows:

The workability is less sensitive to low dosage and the sensitivity increases with the increase of dosage. As an indication, with steel fibre dosage of 25 kg/m³ the workability decrease by about 40% compared to plain concrete. In practice the mix composition of mixes containing high steel fibre dosages should be adjusted to ensure acceptable workability.

The steel fibre dosage has a negligible influence on the compressive strength at 7 and 28 days.

At 28 days, steel fibre dosage has a significant influence on the. As an indication, for a steel fibre dosage of 25 kg/m³ an increase of approximately 29% was obtained (relative to plain concrete).

At 28 days, the effect of steel fibre dosage is considered to have a marginal effect on the flexural strength. As an indication, addition of 30 kg/m³ of steel fibres increases the flexural strength by about 10 % (relative to plain concrete).

Steel fibre dosage has a significant influence on toughness characteristics. As an indication, the after crack strength increases by more than 67% with a steel fibre dosage of 30 kg/m³.

The results of this experiment indicated that the brittle failure mechanism normally associated with concrete could be altered to a more ductile failure mechanism by the addition of relatively low steel fibre dosages. The increased post-cracking toughness of SFRC can be utilised in applications such as concrete pavements and other structures where the consequences of failure are not catastrophic.

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