Effect of pressure after casting on high strength fibre reinforced mortar

Silvio Delvasto*, Antoine E. Naamant and James L. Thronet

Synopsis   This study investigates the effects of applying pressure after casting on the flexural response of high strength fibre reinforced mortar in which up to 5% fibres by volume were premixed. High mortar strength was achieved by reducing mix porosity (low water–cement ratio), adding fly ash and using superplasticisers. Variables included eight different types of fibre, their volume fraction in the mix, two mortar matrices, two values of pressure after casting, and the casting orientation. It is found that pressure improves the proportional limit and the flexural strength of the composite but may lead to a deterioration in its postcracking response and toughness. Composite moduli of rupture of more than 5000 psi (37 MPa) are observed with steel fibres while highest toughness indices of up to 90 are reported with polypropylene fibres. It is concluded that the application of pressure after casting to improve composite properties is not economically justifiable.

Keywords   Fibre cement composites, pressure compaction, steel fibres, polypropylene fibres, glass fibres, carbon fibres, modulus of rupture, toughness, ductility, elastic modulus, mortars (material), strength of materials, failure.

INTRODUCTION

It is generally agreed that the main shortcomings of hydraulic cement matrices (paste, mortar, concrete) are their low tensile strength and brittleness at failure. These shortcomings can be improved by addition of short strong discontinuous fibres leading to what is called a fibre reinforced cementitious composite or fibre reinforced concrete (FRC). Among the most desirable properties of fibre reinforced concrete is its tensile-flexural strength and its toughness or energy absorbing capability to failure. Continuous research is being currently undertaken to improve these properties.

The mechanics of tension strengthening is either due to the elastic extension of the fibres after matrix cracking, such as in the case of polypropylene fibres, or to the fibre pullout resistance such as in the case of steel fibres. Although an increase in tensile strength may lead to a more than proportional increase in toughness should multiple cracking occur, the increase in toughness is attributed primarily to the pullout mechanism of the fibres.

Little work has been published on the use of fibres in

high strength concrete [1, 2]. Here high strength indicates strengths in compression of the order of 10 to 15 ksi (69 to 104 MPa). Because the brittleness of concrete (characterised by its post-peak softening response) increases with its strength, it seems desirable to improve its toughness by addition of fibres. High strength is achieved by a reduction in porosity, hence in water–cement ratio. However, the addition of fibres generally requires higher water content to maintain workability of the mix. Thus a trade-off must be made when using a high volume content of fibres in a high strength cement matrix.

The main objective of this research was to study the effect of pressure after casting on the flexural response of high strength fibre reinforced mortar containing a relatively high volume fraction of fibres. High strength was achieved by the use of low water–cement ratios and a superplasticiser. Variables included eight different types of fibres, their volume fraction in the mix, two mortar matrices, and the casting orientation.

This research is significant for the production of high strength cementitious composites such as in the cement sheet industry (asbestos cement, tiles, etc.,). It is also important if the brittleness of high strength concrete is to be overcome in some structural applications, since the addition of fibres improves significantly the toughness of the material.

EXPERIMENTAL PROGRAMME

The experimental programme explored the influence of various parameters on the static flexural strength of fibre reinforced mortar. These included primarily the pressure-

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compaction after casting, the water–cement ratio, the casting orientation, and the fibre volume and fibre type. The objective was to decrease as much as possible the water–cement ratio (hence increase matrix strength) and increase as much as possible the volume content of fibres while keeping the mix workable. In most of the mixes described the workability (or plasticity) could be characterised by a consistency less than normal. A large number (14) of exploratory mixes were tried [3]. Two are described here (Table 1) and are numbered 4 and 5 as identified in [3]. Thirty-eight series of fibre reinforced mortar flexural beams were made with these two mixes and tested. They are described in Table 2. The first two letters of the code designation of each series represent the fibre type (i.e. P for polypropylene) and the mix number (i.e. 4 or 5). The following letters represent when applicable the variety of fibre (i.e. Polypropylene A, B, or C), whether the specimens were pressed after casting or not (i.e. P for pressed), and a number representing identical series prepared at different times.

Mortar matrix

The two matrices selected have similar dry composition and workability but different water–cement ratios, hence different flexural strengths. The dry mortar consisted of ASTM Type I portland cement, a fine silica sand (Ottawa passing ASTM sieve No. 40), and fly ash. The mix proportions by weight and corresponding flexural and compressive strengths are summarised in Table 1. Note that a type A superplasticiser (trade name Melment) was also used to maintain the desired workability.

Fibres

Several types of fibres were used in the form of randomly distributed discontinuous reinforcement. They are described in Table 3 and include three varieties of polypropylene fibres, carbon fibres in two lengths, steel fibres, glass fibres, and asbestos fibres. Some relevant properties of these fibres as provided by their manufacturer (or as obtained from previous studies) are shown in Table 4.

Specimen preparation

The component materials were mixed using a Hobart type food mixer. Cement and half of the water were first mixed. Then, the sand, fly ash, and the remaining water were added followed by the superplasticiser. The fibres were then slowly dispensed. The fresh mix was cast and compacted in flexural moulds according to three different methods. In the first two methods the specimens were cast either vertically or horizontally (Figure 1a and 1b) in plexiglass moulds and externally vibrated on a vibrating table. This was done to compare differences due to filling direction and compaction. In the third method the specimens were cast horizontally in steel

moulds, vibrated, finished, then immediately put under pressure (Figure 1c) using a universal testing machine. A pressure of either 4.5 N/mm^2 (650 psi) or 9 N/mm^2 (1300 psi) was applied for about 15 minutes to expel surplus water. The pressed beams were 12 in (300 mm) long, 2 in (50 mm) wide and of thickness as measured, ranging from 0.25 to 0.75 in (6 to 19 mm). The nonpressed specimens were 12 in (300 mm) long, 3 in (75 mm) wide and 0.5 in (12.5 mm) thick.

Curing and testing

Following casting the moulds were placed in a humid enclosure (100% RH and 72°F) for 24 hours. The specimens were then removed and stored in a fog room (100% RH and 75°F) for about 60 days. Then they were stored in a laboratory environment for 1 day prior to testing. Testing was undertaken using an Instron Universal Testing machine. Two point loading was applied on a 10 in (250 Mm) span with a 4 in (100 mm) constant bending moment zone (Figure 2). The load–deflection curves were automatically plotted on an X–Y recorder. The beams were generally loaded to failure or up to 0.5 in (12.5 mm) deflection, whichever occurred first. Each series of tests comprises three to six specimens. Observed results are described next.
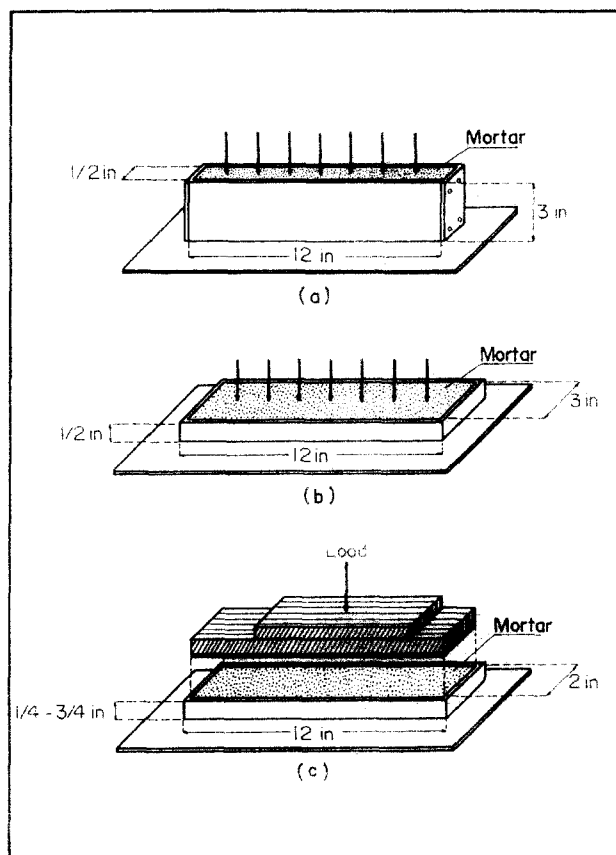

Figure 1 Methods of specimen casting. (a) Vertical, (b) Horizontal, (c) Pressed

Table 1 Properties of mortar mixes used

Components	Ratio by weight	Mix 4	Mix 5
Type I portland cement, C	C = 1	1.00	1.00
Fine silicious (Ottawa) sand, S	S/C	0.20	0.20
Fly ash, FA	FA/C	0.20	0.20
Water, W	W/(C+FA)	0.30	0.24
Superplasticiser, Melment	SP/C	0.023	0.05
Compressive strength, 90 days, psi (MPa)		11278(77.8)	14609(100.8)
Flexural strength, 60 days, psi (MPa)		732 (5.0)	978 (6.7)
Tensile strength, 28 days, psi (MPa)		549 (3.8)	584 (4.0)
Specific gravity		2.21	2.24

Table 2 Test series code designation and characteristics

Series code designation	Fibre	Mix	Process	Volume fraction of fibres, V_f%
P4AP1	Polyprop.A	4	Pressed	5.0
P4AP2	Polyprop.A	4	Pressed(*)	5.0
P4A	Polyprop.A	4	Hand Laid	5.0
P5A5P	Polyprop.A	5	Pressed	5.0
P5A5	Polyprop.A	5	Hand Laid	5.0
P5A3P	Polyprop.A	5	Pressed	3.0
P5A3	Polyprop.A	5	Hand Laid	3.0
P4BP	Polyprop.B	4	Pressed	2.5
P4B	Polyprop.B	4	Hand Laid	2.5
P5BP	Polyprop.B	5	Pressed	3.7
P5B	Polyprop.B	5	Hand Laid	3.7
P4CP	Polyprop.C	4	Pressed	4.0
P4C	Polyprop.C	4	Hand Laid	4.0
P5CP	Polyprop.C	5	Pressed	3.1
P5C	Polyprop.C	5	Hand Laid	3.1
S4P	Steel	4	Pressed	5.0
S4	Steel	4	Hand Laid	5.0
S5A1	Steel	5	Hand Laid in Horizont. mould	5.0
S5A5	Steel	5	Hand Laid in Vertical mould	5.0
S5BP	Steel	5	Pressed	2.1
S5B	Steel	5	Hand Laid	2.1
C4AP	Carbon A	4	Pressed	1.5
C4A	Carbon A	4	Hand Laid	1.5
C4BP	Carbon B	4	Pressed	1.7
C4B	Carbon B	4	Hand Laid	1.7
C5AP	Carbon A	5	Pressed	1.9
C5A	Carbon A	5	Hand Laid	1.9
C5BP	Carbon B	5	Pressed	1.9
C5B	Carbon B	5	Hand Laid	1.9
G4P	Glass	4	Pressed	5.0
G4	Glass	5	Hand Laid	5.0
G5P	Glass	5	Pressed	2.5
G5	Glass	5	Hand Laid	2.5
A5P	Asbestos	5	Pressed	1.9
A5	Asbestos	5	Hand Laid	1.9
M4P	Plain Mortar	4	Pressed	0.0
M4	Plain Mortar	4	Hand Laid	0.0
M5P	Plain Mortar	5	Pressed	0.0
M5	Plain Mortar	5	Hand Laid	0.0

The Pressure in the Pressed Series was 50 kg/cm² except (*) pressed at 100 kg/cm².

TEST RESULTS AND DISCUSSION

To eliminate the effect of specimen geometry on the load deflection response of the beams tested, all results are reported in terms of the equivalent elastic flexural stress as obtained from the following equation:

$$\sigma = \frac{M}{Z} = \frac{9P}{bd^2} \qquad (1)$$

where σ = equivalent elastic flexural stress
M = magnitude of moment in constant moment zone
Z = section modulus
b = beam width
d = beam depth
P = applied load

Table 5 summarises the average results obtained. The stress at the limit of proportionality (LOP) corresponds to first cracking and was obtained at the point of deviation from the initial linear portion of the load deflection curve. The modulus of rupture was obtained from the maximum load after cracking. Corresponding deflections are also reported in Table 5. The influence of various parameters on the load deflection response is described next.

Effect of pressure

The effect of pressure on the load deflection response was generally beneficial prior to first cracking (except in one case) and detrimental thereafter as shown in Figures

Table 3 Description of fibres

Fibre	Type	Fibre diameter (or equivalent) inch (mm)	Fibre length in (mm)	Supplier
Polypropylene A	Chopped fibres two-ply twisted ribbon yarn	2×500D*	1 (25)	AMOCO
Polypropylene B	Mesh Type A–5	—	0.75 (19)	Forta Fibre, Inc.
Polypropylene C	Resin European Fibres, Chopped Staple	2.8D	0.8 (20)	AMOCO
Carbon A	Type C–20–PVP Celion 12000 (12000 Filaments)	0.28×10^{-3} (7×10^{-3})	0.75 (19)	Celanese
Carbon B	Type C–6–PVP Celion 12000 (12000 Filaments)	0.28×10^{-3} (7×10^{-3})	0.25 (6)	Celanese
Steel	Smooth brass coated wire, Type Hc Br	0.016 (0.41)	0.75 (19)	National Standard C
Glass	Chopped Strand Type 3029 (203 Filaments)		0.50 (12.5)	Owens Corning Glass
Asbestos	While (Chrysotile)	$0.02–30 \ 10^{-3}$mm	— —	

*Denier: Mass in grams of 9000 m of yarn.

Table 4 Properties of fibres used

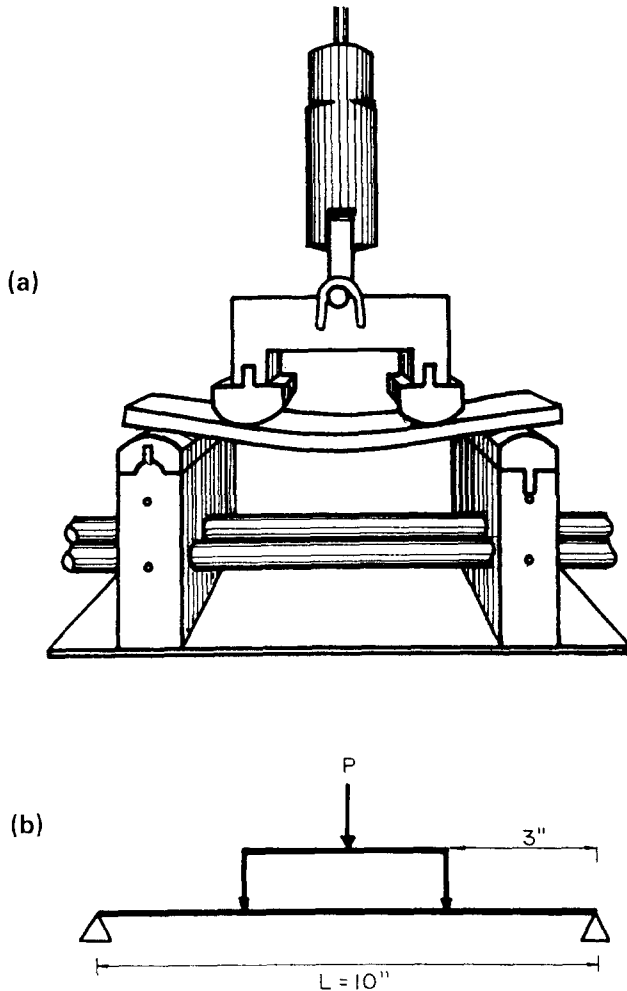| Properties of fibres	Specific gravity	Tensile strength Ksi (MPa)	Elastic modulus 10^3 Ksi $(10^3$ MPa)	Ultimate elongation percent
Polypropylene	0.91	80–111 (552–759)	0.98 (6.7)	21
Carbon	1.77	440–515 (3000–3500)	34 (235)	1.5
Steel Wire	7.86	100–120 690–833	30 (207)	7
Glass	2.70	150–180 (1034–1241)	10 (69)	2–3.5
Asbestos	2.55	—	24 (164)	2–3

(a)

(b)

Figure 2 Test set-up. (a) Flexural specimen underload
(b) Loading arrangement of flexural beams

3 and 4. It can be seen from these figures that both the stress at first cracking and the slope of the stress deflection curve (or equivalently the elastic modulus) are, on the average, larger for the pressed series than for the unpressed ones. However, the properties of the pressed specimens deteriorate more rapidly after cracking leading to a smaller modulus of rupture (except for steel fibres) and a substantially smaller toughness due to premature failure. These effects are particularly noticeable in the case of polypropylene fibres but less significant for steel, glass, and carbon fibres (Figures 3 and 4).

References about fibre reinforced concrete performance when subjected to pressure after casting are scarce. Waller [5] subjected carbon fibre reinforced cement samples to pressure after casting to expel surplus water and entrapped air. He reported no improvement in strength. He attributed this result to the channelling produced by water flow which was large in relation to sample thickness.

In this study pressed specimens showed lower post-cracking stress and toughness than unpressed ones suggesting that pressure may have led to some
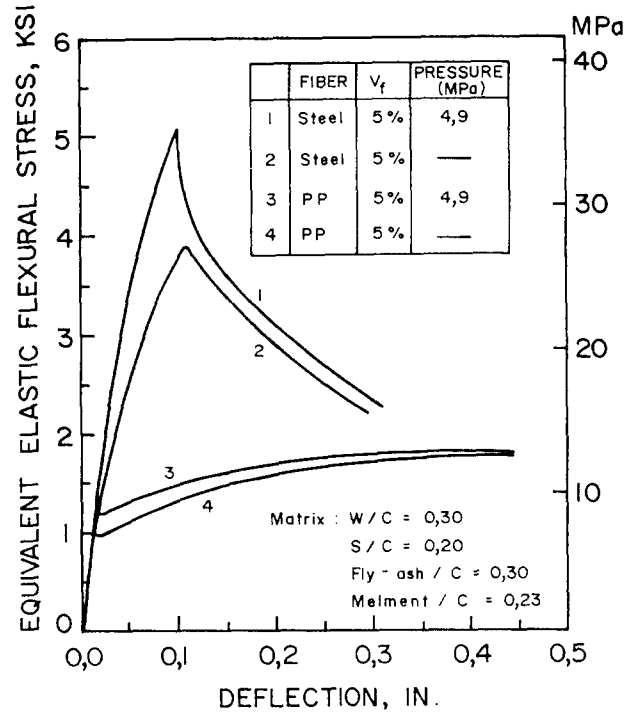
Figure 3 Typical effect of pressure casting on the load-deflection curve of steel and PP fibre reinforced mortar
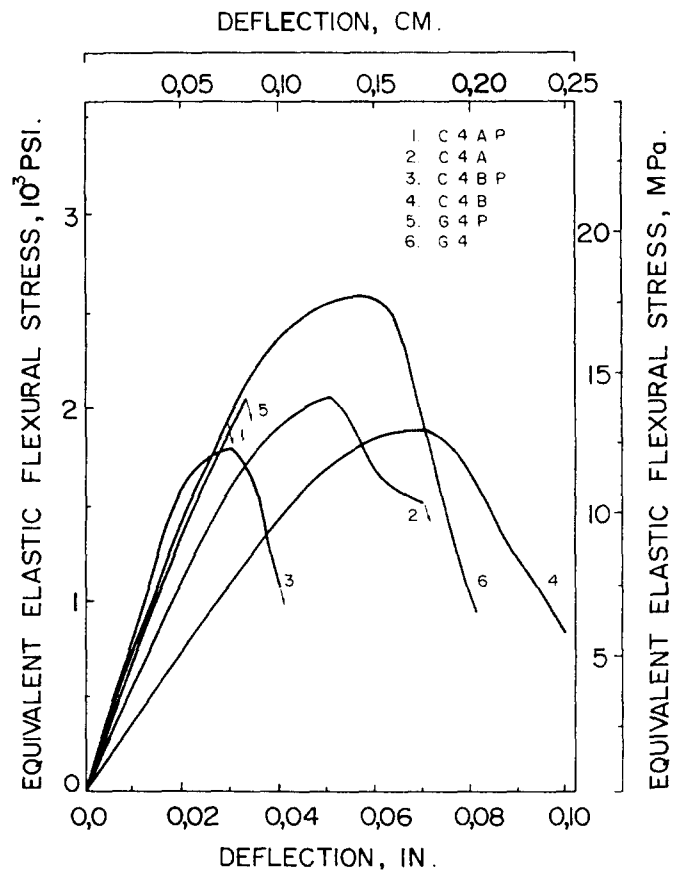
Figure 4 Typical effect of pressure casting on the load-deflection curve of glass and carbon fibre reinforced mortar

deterioration in either the bond at the fibre-matrix interface or the fibre itself. High fibre concentrations and excess water loss due to pressure may be other reasons for such deterioration.

Concentration of fibres due to pressure beyond a certain limit may be a relevant cause for a reduction in strength and toughness. Naaman and Shah [6] found that the pullout resistance (hence composite toughness) per fibre decreases when the number of fibres pulling out from the same area increases. X-ray analysis by Walkus *et al.* [7] indicates that failure cracks pass through scattered fibre zones. Patton and Whittaker [8] established that a group of fibres spaced closely enough interact to form a small area of high stiffness hence stress concentration. When this stress exceeds the strength of the inclusion, the region nucleates a failure

crack, supporting the conclusion that tensile strength diminishes at very high fibre content.

Bleeding was induced during application of pressure. Ritchie and Rahman [9] analysed the extent of bleeding water in polypropylene and steel fibre reinforced concrete. They observed that bleeding water was held around individual fibres, hence a reduction in their bond strength. The amount of bleeding water decreased with an increase in fibre content and depended on the type and size of fibre. As bleeding is related to surface tension, the smoother the fibre (such as steel) the less bleeding water is retained and the more bleeding is observed.

A reduction in porosity of the cement paste (hence an increase in strength) can be achieved, as done in this study, by a reduction in the water–cement ratio and by

Table 5 Summary of flexural test results

| Series code | Limit of proportionality (first crack) | | Modulus of rupture (MOR) (Maximum load) | | | |
| | Average strength Psi (MPa) | Average deflection Inches (mm) | strength Psi (MPa) | | deflection Inches (mm) | |
			Best	Average	Best	Average
P4AP1	1066 (7.4)	0.020 (0.51)	1899 (13.0)	1823 (12.6)	0.36 (9.14)	0.35 (8.89)
P4AP2	1150 (7.9)	0.030 (0.76)	1540 (10.6)	1440 (9.9)	0.35 (8.89)	0.37 (9.40)
P4A	860 (5.9)	0.020 (0.51)	3036 (20.9)	2490 (17.2)	1.05 (26.7)	0.80 (30.32)
P5A5 P	808 (5.6)	0.017 (0.43)	2100 (14.5)	2070 (14.3)	0.02 (0.51)	0.02 (0.51)
P5A5	1150 (7.9)	0.015 (0.38)	2772 (19.1)	2232 (15.4)	0.31 (7.87)	0.38 (9.65)
P5A3 P	1198 (8.3)	0.013 (0.33)	1855 (12.8)	1855 (12.8)	0.06 (1.52)	0.06 (1.52)
P5A3	1050 (7.2)	0.018 (0.46)	1643 (11.3)	1500 (10.3)	0.37 (9.4)	0.38 (9.65)
P4BP	1263 (8.7)	0.017 (0.43)	1478 (10.2)	1333 (9.2)	0.14 (3.56)	0.12 (3.05)
P4B	957 (6.6)	0.030 (0.76)	1183 (8.2)	1158 (8.0)	0.37 (9.40)	0.41 (10.41)
P5BP	1065 (7.3)	0.020 (0.51)	1769 (12.2)	1556 (10.7)	0.21 (5.33)	0.17 (4.32)
P5B	907 (6.3)	0.018 (0.46)	2220 (15.3)	1848 (12.7)	0.28 (7.11)	0.26 (6.60)
P4CP	1100 (7.6)	0.015 (0.38)	1497 (10.3)	1491 (10.3)	0.08 (2.03)	0.14 (3.56)
P4C	831 (5.7)	0.020 (0.51)	1460 (10.1)	1410 (9.7)	0.54 (13.72)	0.52 (13.21)
P5CP	873 (6.0)	0.023 (0.58)	1246 (8.6)	1072 (7.4)	0.13 (3.3)	0.09 (2.29)
P5C	959 (6.6)	0.022 (0.56)	1631 (11.2)	1529 (10.5)	0.45 (11.43)	0.39 (9.91)
S4P	1250 (8.6)	0.017 (0.43)	5139 (35.4)	5139 (35.4)	0.10 (2.54)	0.10 (2.54)
S4	1100 (7.6)	0.020 (0.51)	4274 (29.5)	3878 (26.7)	0.15 (3.81)	0.11 (2.79)
S5A1	1020 (7.0)	0.012 (0.30)	5094 (35.1)	4581 (31.6)	0.11 (2.79)	0.10 (2.54)
S5A5	1020 (7.0)	0.012 (0.30)	5798 (40.0)	5136 (35.4)	0.12 (3.05)	0.12 (3.05)
S5BP	1245 (8.6)	0.020 (0.51)	1589 (11.0)	1538 (10.6)	0.03 (0.76)	0.03 (0.76)
S5B	1117 (7.7)	0.013 (0.33)	2037 (14.0)	1897 (13.2)	0.06 (1.52)	0.05 (1.27)
C4AP	1066 (7.4)	0.017 (0.43)	1973 (13.6)	1920 (13.2)	0.03 (0.76)	0.03 (0.76)
C4A	1070 (7.4)	0.020 (0.51)	2391 (16.5)	2052 (14.2)	0.07 (1.78)	0.05 (1.27)
C5AP	1092 (7.5)	0.020 (0.51)	2063 (14.2)	1628 (11.2)	0.03 (0.76)	0.03 (0.76)
C5A	1150 (7.9)	0.016 (0.41)	1814 (12.5)	1677 (11.6)	0.04 (1.02)	0.03 (0.76)
C4BP	1150 (7.9)	0.017 (0.43)	1792 (12.4)	1792 (12.4)	0.03 (0.76)	0.03 (0.76)
C4B	1150 (7.9)	0.030 (0.76)	1882 (13.0)	1882 (13.0)	0.07 (1.78)	0.07 (1.78)
C5BP	1278 (8.8)	0.018 (0.46)	1969 (13.6)	1758 (12.1)	0.03 (0.76)	0.03 (0.76)
C5B	1100 (7.6)	0.018 (0.46)	2538 (17.5)	2337 (16.1)	0.05 (1.27)	0.05 (1.27)
G4P	1036 (7.1)	0.016 (0.41)	2035 (14.0)	2035 (14.0)	0.03 (0.76)	0.03 (0.76)
G4	996 (6.9)	0.012 (0.30)	2580 (17.8)	2472 (17.0)	0.06 (1.52)	0.06 (1.52)
G5P	1260 (8.7)	0.020 (0.51)	1821 (12.6)	1624 (11.2)	0.02 (0.51)	0.02 (0.51)
G5	1000 (6.9)	0.018 (0.46)	1631 (11.2)	1487 (10.3)	0.03 (0.76)	0.02 (0.51)
A5P	1000 (6.9)	0.015 (0.38)	1220 (8.4)	1111 (7.7)	0.03 (0.76)	0.02 (0.51)
A5	980 (6.8)	0.017 (0.43)	1140 (7.9)	1062 (7.3)	0.02 (0.51)	0.02 (0.51)

pressure compaction. However the addition of large amount of fibres tends to entrain or entrap air, increasing the porosity of the matrix. It seems that both air entrapment and bleeding will tend to balance the beneficial effects of reduced porosity and pressure casting. Hence a trade-off must be achieved in practice.

Effect of matrix strength

An increase in matrix strength is expected to lead to an increase in diversification at the fibre-matrix boundary. Everything else being equal it led to significant increases in the modulus of rupture and in the toughness of the composite. This is illustrated in Figures 5 and 6 for the series reinforced with polypropylene and steel fibres. The increase is primarily attributed to improvement in bond strength [10, 11], thus fibre efficiency. However as observed from Tables 5 and 6 it was often more than proportional to the increase in matrix tensile strength especially for the case of steel fibres. It is believed that, at high concentrations, steel fibres tend to interact between each other providing resistance even without the presence of the matrix.

Effect of casting orientation and fibre content

Everything else being equal specimens cast vertically along their width led to higher values in strength and

toughness than specimens cast horizontally. A typical example is shown in Figure 7. This may be attributed to the better compaction achieved in vertically cast specimens, and, as reported by Moens and Nemegeer [12], to induced fibre orientation during the filling process.

As expected the higher the volume fraction of fibres the higher the modulus of rupture and the toughness of the composite. Typical results for polypropylene and steel fibre reinforced mortar beams are shown in Figures 8 and 9. A volume fraction of fibres of 5% was about the maximum that could be mixed for the given matrix. For the same volume fraction of fibres, steel fibres led to a composite modulus of rupture about twice that achieved by polypropylene fibres. Moreover, because steel fibres are very stiff, the slope of the initial portion of the load
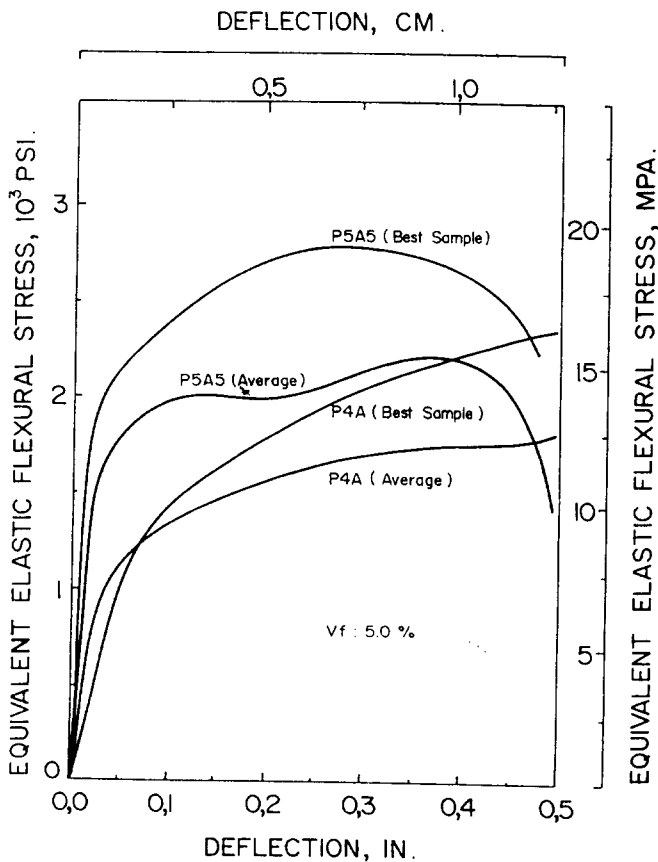
Table 6 Summary of average values of toughness index (Ref.3)

Series code	Flexural toughness index at deflection of:	
	0.075 in (1.9mm)	0.5 in (12.5mm)
P4AP1	6.1	59.1
P4AP2	2.5	23.6
P4A	6.2	88.8
P5A5P	7.0	17.6
P5A5	8.6	80.9
P5A3P	5.1	12.9
P5A3	7.0	72.5
P4BP	6.0	25.2
P4B	4.4	32.2
P5BP	4.3	12.6
P5B	5.3	41.0
P4CP	11.4	41.6
P4C	8.0	54.6
P5CP	6.3	18.7
P5C	7.9	70.9
S4P	3.5	27.9
S4	1.5	18.0
S5A1	4.5	30.3
S5A5	2.6	21.8
S5BP	5.4	27.4
S5B	8.3	47.6
C4AP	1.9	—
C4A	3.8	—
C4BP	4.6	—
C4B	3.0	—
C5AP	2.4	—
C5A	6.4	—
C5BP	1.3	—
C5B	1.3	—
G4P	3.6	—
G4	6.5	—
G5P	3.3	—
G5	4.6	—
A5P	3.7	—
A5	3.6	—

Figure 5 Effect of matrix compressive strength on the load-deflection response of PP fibre reinforced mortar
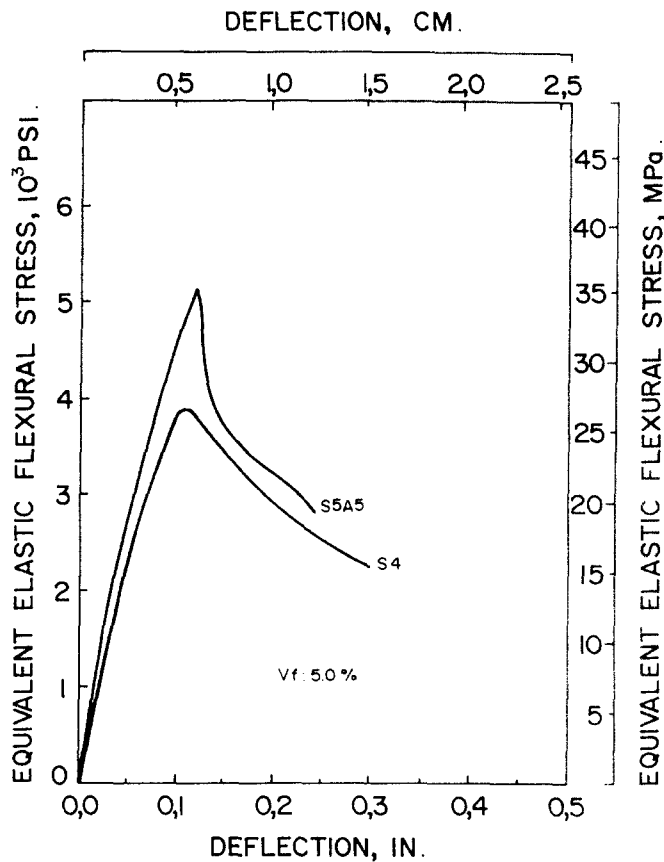
Figure 6 Effect of matrix compressive strength on the load-deflection response of steel fibre reinforced mortar
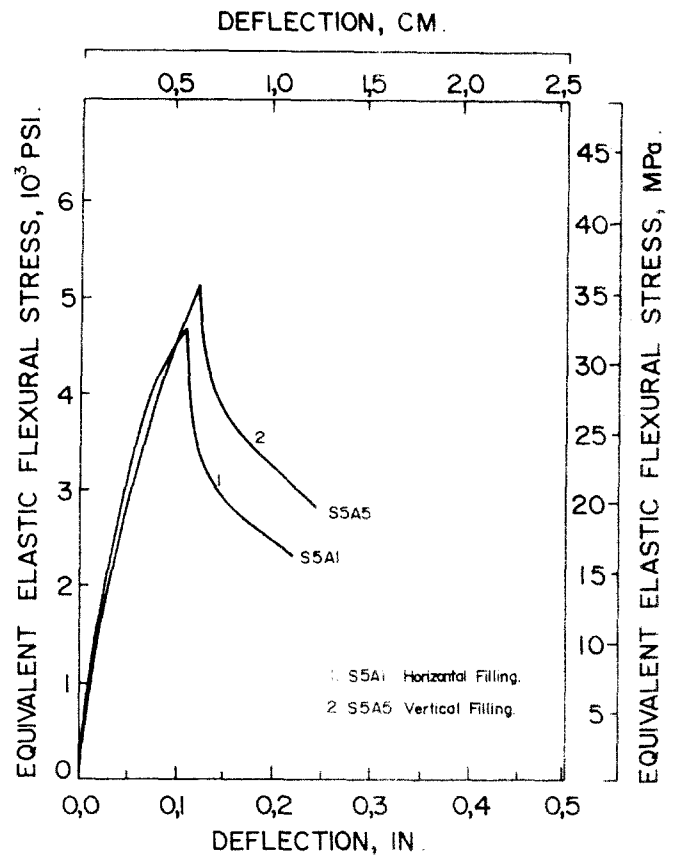

Figure 7 Effect of direction of casting on the load-deflection response of steel fibre reinforced mortar

deflection curve remains quite linear up to very high stresses. This explains the high values of LOP reported in Table 4 which may not be real but just due to the inaccuracy of the method of measurement when a high volume of steel fibres is used.

Toughness

One of the main benefits of adding fibres to a brittle matrix is to improve the energy absorption or toughness of the composite. Various methods to evaluate toughness have been proposed in the technical literature [4, 14–20]. So far, the most convenient one leads to a relative measure called toughness index and is recommended by ACI Committee 544 on fibre reinforced concrete [14] and the new ASTM Standard C1018–85 [20]. The toughness index is defined as the ratio of the area under the load deflection curve of the composite up to a specified deflection, to that up to the proportional limit or first crack strength. The latter value represents the energy absorbed by the unreinforced matrix. The deflection specified by ACI Committee 544 to determine the numerator is 0.075 in (1.9 mm) but it assumes different specimen dimensions and flexural stiffness. The toughness index for the test series of this study was determined assuming two values of limiting deflections,

namely 0.075 in (1.9 mm) and 0.5 in (12.5 mm). As observed from the stress–deflection curves (Figures 3 to 7), the latter value is more realistic for the specimens dimensions used here. Table 6 summarises the results obtained. Note that glass, carbon and asbestos fibre reinforced composites collapsed at a deflection less than 0.075 in (1.9 mm). Hence the same toughness index is recorded for 0.075 in 1.9 mm and 0.5 in (12.5 mm) deflections. It can also be seen that the addition of fibres to a mortar matrix leads to up to two orders of magnitude increase in its flexural toughness. The highest toughness index (88.8) was achieved with polypropylene fibres and was about twice the highest achieved by steel fibres (47.6). A much smaller toughness index ranging from 1.3 to 6.5 was obtained by the use of carbon, glass, or asbestos fibres.

It is noted that the new ASTM test [20] for flexural toughness was not followed here as it was not available at the time the experimental investigation took place.

CONCLUSIONS

On the basis of this study the following conclusions are drawn:

1. The application of short term (about 15 minutes) pressure of up to 1300 psi (9 MPa) to a freshly cast fibre
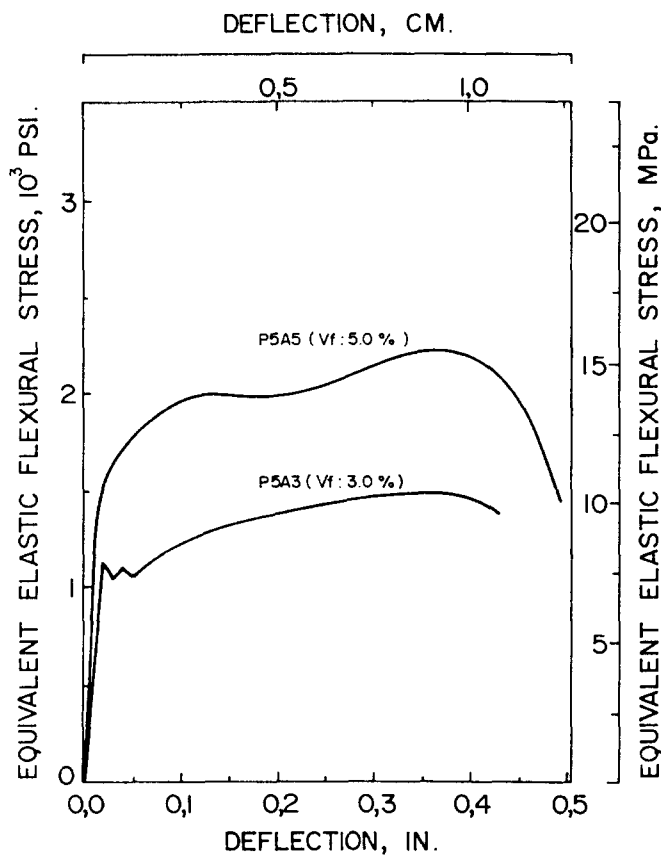
Figure 8 Effect of fibre content on the load-deflection response of PP fibre reinforced mortar
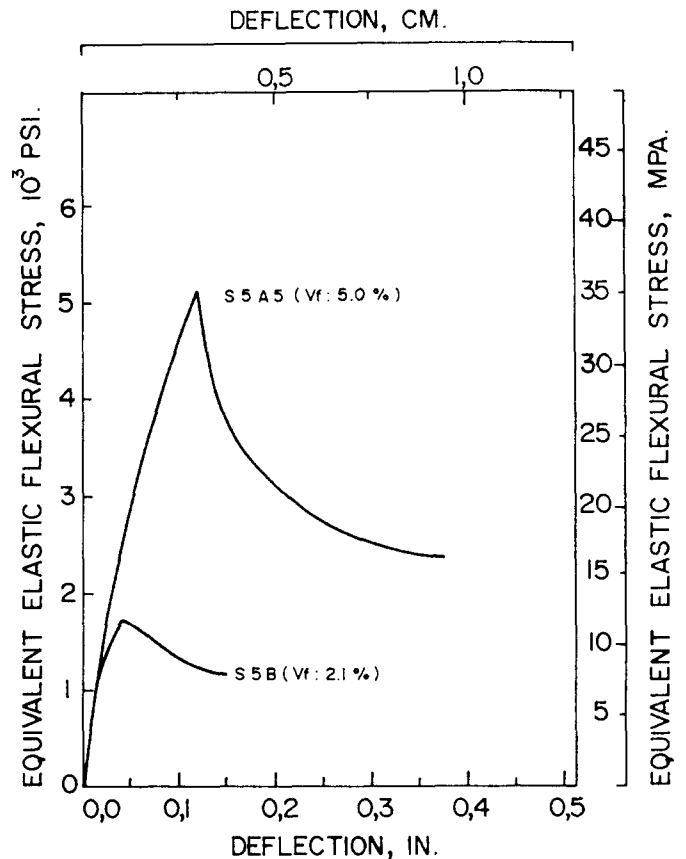

Figure 9 Effect of fibre content on the load-deflection response of steel fibre reinforced mortar

reinforced mortar leads to a slight increase in the proportional limit and elastic modulus of the resulting composite. However, it may also lead to a decrease in its modulus of rupture and its toughness.

2. The benefits of applying pressure after casting to fibre reinforced mortar do not seem to justify the cost of implementing in practice such a process. Improvement in matrix and composite strength can be more effectively obtained by controlling the water–cement ratio of the mix, selecting the type and proportion of superplasticiser, and adding, the proper amount of mineral admixtures.

3. Everything else being equal, an increase in the strength of the mortar matrix leads to an increase in the proportional limit, modulus of rupture and toughness of the resulting fibre reinforced composite.

4. Increase in both strength and toughness are observed when the direction of casting the tensile (wider) face of the flexural specimen is changed from horizontal to vertical.

5. Both the strength and toughness of fibre reinforced mortar increase with an increase in the volume fraction of fibres. However, in premixed fibre cement composites, an optimum limit may be obtained beyond which addition of fibres will not lead to any improvement.

6. In comparing toughness values for different composites as derived from flexural tests, it is essential that the comparison be made at different deflections. Some fibres led to better composite performance at small deflections (steel, glass) while others (polypropylene) were superior for large deflections. This is also recommended in the new ASTM standard test for flexural toughness of fibre reinforced concrete [20].

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