Compressive strength of concrete with polypropylene fibre additions

Alan E. Richardson
School of Built Environment, Northumbria University, Newcastle upon Tyne, UK

Abstract

Purpose – Conflicting claims have been made in relation to the effects of polypropylene fibres on the compressive strength of concrete. The purpose of this paper is to examine the effects on compressive strength of various dosages of monofilament polypropylene fibres when used in concrete. Compressive strength is widely used as the key indicator of concrete quality and therefore needs accurate determination. Monofilament fibres and air entrainment provide a similar function in that they provide freeze/thaw protection, they are both compared against a plain concrete sample to determine relative strength and density.

Design/methodology/approach – Two different concrete design strengths (medium and high) were examined with varying amounts and types of polypropylene fibre fraction/volume to establish a common link between fibre additions and reduced final compressive strength.

Findings – The findings from the test programme showed a linear reduction in strength which was observed as being directly related to fibre inclusion in concrete. Density was also found to be reduced with the addition of fibres in a similar degree to that of air entrainment.

Research limitations/implications – The lower density of concrete with polypropylene fibre additions was not scientifically explained and this aspect currently forms part of a long term freeze/thaw research programme, which will examine pore spacing and void formation compared to plain concrete.

Originality/value – This paper is of interest to clients, concrete manufacturers, concrete additive manufacturers, designers, surveyors and specifiers who need to know what effect polypropylene fibre additives have upon the final compressive strength.

Keywords Concretes, Density, Compressive strength, Design

Paper type Research paper

Introduction

If an additive to concrete imparts enhanced qualities to concrete with regard to reduced absorption, reduced ion flow and improved freeze/thaw protection leading to improved durability, but reduces compressive strength, what level of compressive strength reduction will be experienced? What effect will this have on structural design and what mechanism causes strength reduction, and will this affect durability?

This paper examines the effects of variable dosages of polypropylene fibres when used in low/medium and medium/high strength concrete with regard to compressive strength, compared to plain and air entrained concrete.

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The Building Research Establishment (2000) stated, "strength tests on specimens found the cube compressive strength of concrete containing polypropylene fibres to be significantly reduced because of the resulting lower density" (this needs to be allowed for in design, however compressive strength and durability are not necessarily directly related). This statement does not concur with Alhozaimy *et al.* (1996) who suggest, polypropylene fibres have no statistically significant effect on compressive strength. The above statements were key motivators for influencing this paper. Aulia (2002) states:

> The use of a certain amount of fibres in the concrete ... did not influence detrimentally the main mechanical properties of high strength concretes.

The investigation into the use of polypropylene fibres with high strength concrete suggests the effects of fibres in concrete with a lower strength may perform differently to that of concrete with a high strength and this aspect is investigated within this work.

Trials carried out by Warner (1995) with a variety of concrete samples of various types of fibrillated polypropylene fibre and glass fibre additions, examining flexural and compressive strength were carried out between 1 and 28 days from batching. The concrete as used by Warner was of an approximate compressive strength around 45 N/mm^2 with a 27 per cent cement replacement of pulverised fuel ash and a water cement ratio of 0.45. Fibre dosage was 0.9 kg/m^3 and the fibres were supplied by Fibermesh, being 6,130 collated fibrillated 100 per cent polypropylene fibres in lengths of 19 mm, 38 mm and 50 mm.

For the purpose of this analysis, the fibreglass concrete samples have been ignored as the comparisons made within the work appertain to polypropylene fibre use in concrete only. Compressive strength testing was in accordance with BS 1881: Part 116: 1983. Comparing the performance of the concrete with variable fibre additions to that of natural or plain concrete and significant values were observed. These being, 19 mm length fibres perform better than the 38 mm and 50 mm fibres at 3, 7, 14 and 28 day intervals. The percentage changes are shown in Table I.

The final comparison between strengths at 28 days, showed a marginal increase in compressive strength of 5 per cent, which is statistically insignificant given the variable nature of concrete.

As previously stated, the compressive strength of polypropylene fibre reinforced concrete is suggested to be marginally reduced, although a possible reason for lower compressive strength and lower density when using polypropylene monofilament fibres has been stated by Gold (2000) and this is that, "Fibres actually entrain small amounts of air as a result of the surface treatment they receive in the manufacturing process", this provides a plausible reason for the lower density and subsequent compressive strength. Although in the author's opinion this is not a conclusive

Time cured	Positive improvement (%)	Negative reduction (%)
3 days	41	
7 days	53	
14 days		4
28 days	5	

explanation, due to the many variables contained within concrete and requires further exploration.

If concrete with a monofilament fibre addition were responsible for air entrainment then, monofilament polypropylene fibre concrete may behave in a similar way to that of air entrained concrete which "at constant water-cementing materials ratios, increases in air will proportionally reduce strength" (Cement Association of Canada, 2006).

For moderate strength concrete, each percentile of entrained air reduces the compressive strength about 2 per cent to 9 per cent (Klieger, 1956). Actual strength varies and is affected by the cementing materials source, admixtures, and other concrete ingredients.

Alhozaimy (1996, p. 85) states:

> Contradictory test results have been reported by different investigators regarding the effects of polypropylene fibres on the compressive and flexural strengths of concrete materials. Differences in results may have been caused by the differences in matrix composition, polypropylene fibre type and volume fraction and manufacturing conditions.

An example of the divergence of statistical test data, is given by comparison of work by Mindness and Vondran (1988) and Hughes and Fattuhi (1976), whereby Mindness and Vondran state compressive strength is increased by 25 per cent and Hughes and Fattuhi state, compressive strength decreases.

The ambiguity and divergence of results make for a compelling case for further laboratory testing work to establish a better understanding of the effects polypropylene fibres have when used in the concrete matrix.

Concrete with monofilament polypropylene fibres

Concrete with polypropylene fibre additions is claimed to have the following advantages: early age crack suppression; lower water demand; consistency of mix; impact resistance; increased strain to failure; better curing due to water retention; in certain circumstances the elimination of the need for secondary reinforcement for crack control (particularly when using crimped/structural fibres); cost advantage over steel fibre reinforcement; a fine crack free finish; more water permeable resistant; better workability and an advantage in longevity and lower life cycle costs, both financial and environmental. One area not often publicised is that of reduction of compressive strength when polypropylene fibres are used in concrete.

From examination of Agrement certificate No 92/2857 (BBA, 2000) conclusions were made with regard to durability and resistance to freeze/thaw and these are shown below:

> Initial surface absorption tests (ISAT), conducted in accordance with BS 1881:5:1970, water absorption to BS 1881: part 122: 1983 and results of other tests on concrete cores, indicate that the fibres have a small but generally positive effect in reducing water absorption. Tests conducted in accordance with BS 5075: part 2: 1982 indicate that Fibermesh concrete has a significantly greater resistance to frost attack than concrete made from equivalent plain mix.... Test data examined by the BBA (British Board of Agrement) indicate that the presence of Fibermesh fibres in conventional concrete mixes reduces the amount of plastic shrinkage, cracking and bleeding in its plastic state, and improves the resistance to impact, surface abrasion, and freeze/thaw resistance of the hardened concrete. Fibermesh concrete is generally more durable than plain concrete to the same mix design. Test results indicate that

Fibermesh concrete, may be considered as an alternative to air entrained concrete where freeze/thaw resistance is required.

This statement of the performance of concrete with polypropylene fibre additions, shows there is a clear significant improvement in performance of the plain concrete product. The BBA certificate goes on to describe the type of fibres used in these tests and they were both fibrillated and monofilament, both fibres have similar characteristics with regard to durability, despite the lowering of compressive strength.

Experimental programme

Manufacturers have marketed a mixed structural and monofilament polypropylene fibre addition to external concrete, claimed to provide enhanced durability. The mixed fibre test (Test 1) for compressive strength formed the start of the investigation when used in medium/high strength concrete, to see if compressive strength was affected with the addition of low density polypropylene fibres.

A lower strength concrete with fibre additions (Test 2) was examined to see what effect polypropylene fibres would have when concrete strength was reduced. To reduce the variables and assist in examining the data, a second series of tests were carried out with a single fibre type at varying dosages to examine the effects of polypropylene fibres on final 28 day compressive strength, using a weaker mix design. The three sets of fibre concrete data were examined against air entrained concrete and plain concrete to see if there was a common strength and density reduction.

The final compressive strength test (Test 3) was to examine a large set of data with a normal polypropylene fibre addition (0.9 kg/m^3) used in medium/high strength 28 day cured concrete. A paired comparison test was used to evaluate the results between plain and concrete with monofilament fibre additions.

Following the first test to establish a link between polypropylene fibre addition and reduced compressive strength, test series 2 and 3 examined density and compressive strength. The findings showed a significant reduction in density with the use of fibre reinforced concrete when compared to plain concrete. Tests (Test 4) were carried out to examine the air content of concrete with fibre additions, whilst taking measurements of compressive strength and the plastic density, to investigate the association between low density and air content. The test programme is shown in Table II.

The test programme was designed to provide an overview of how polypropylene fibres when used in concrete, affect compressive strength of concrete using varying fibre types and fractions and when used in different concrete strengths. Density and air content were examined to see if there was a link between reduced density using fibres in concrete and the air content of concrete in a plastic state.

Compressive strength test programme comparing fibre concrete against plain concrete

Test	Density examined	Sample size per type of concrete	Fibre types per batch	Dosage (variations)	Concrete strength
1	No	5	2	2	Medium/high
2	Yes	5	1 plus air	3	Low/medium
3	Yes	32	1	1	Medium/high
4	Yes	2	1 plus air	1	Medium/high

Test 1. Compressive strength of crimped polypropylene structural fibre and polypropylene monofilament fibre combination, in a medium to high strength concrete

Test 1 was an introduction into the effects of polypropylene fibres when used in concrete with regard to compressive strength. The test examined recent fibre admixtures as used commercially as shown in batch B and batch C to observe the effects of increased doses of fibres with regard to compressive strength.

BS 1881 Testing Concrete: Part 116: 1983 *Method for determination of Compressive Strength of Concrete* was used to examine strength differences between plain and fibre reinforced concrete. 15 No cubes were manufactured to an identical design mix. All of the concrete was batched simultaneously then the plain and fibre concrete was re-mixed for 4 minutes to ensure the same mixing time was given to each batch.

The design mix was 370 kg of CEM 1, 675 kg of coarse sand, 1008 kg of 20 mm gravel, with a water cement ratio of 0.55 and a fibre addition where applicable of varying fractions. Slump readings taken to the nearest 10 mm for the above mix were:

- A 50 mm;
- B 30 mm; and
- C 10 mm.

The concrete samples were left covered with visqueen for 24 hours after which they were separated from their mould and transferred into a curing tank at 20°C.

After 28 days the cubes were taken from the curing tank, wiped clean to remove any loose grit or extraneous material, particularly those faces that were in contact with the platens. Then the cube was carefully centred on the platens prior to the load being applied. A constant loading rate of the compression testing equipment was 405 kN/min/m^2 and the maximum load was recorded prior to the calculation of the final compressive strength as shown in Table III. All cubes exhibited normal failure throughout all tests.

Plain concrete A	Structural and mono fibre concrete B	Structural and mono high dose fibre concrete C	Strength reduction from plain concrete B and C across the sample (%)
42.7	37.6	31.7	12 and 26
41.5	36.4	35.8	12 and 14
42.1	38.2	34.1	9 and 19
41.6	36.1	34.5	12 and 17
42.7	37.6	31.7	12 and 26
Average values down the sample			
42.12	37.18	33.56	11.4 and 20.4

Notes: 1 = A – plain concrete; 2 = B – concrete with crimped/structural fibres 50 mm long (dosage rate 6 kg/m^3) and 35 micron diameter monofilament fibres 12 mm long (dosage rate 0.9 kg/m^3); 3 = C – concrete with crimped/structural fibres 40 mm long (dosage rate 12 kg/m^3) and 22 micron diameter monofilament fibres 19 mm long (dosage rate 6 kg/m^3)

micro cracking because of their low modulus of elasticity compared to the cement matrix. The formed mechanical bond with the cement matrix is thus low".

Test 2. Compressive strength test procedure and specimen manufacture for single monofilament fibre type at varying fractions for low/medium strength concrete

The test examines the most commonly used commercial dose of monofilament polypropylene fibres as used in concrete, with lower and higher dosages to examine what effect a change of fibre volume/fraction has with regard to compressive strength. Aulia (2002) stated "there was little change in performance with fibres used in high strength concrete", therefore the question to be addressed in this section was to find out if the same performance criteria existed with lower strength concrete.

The cube specimens were batched in a 85 litre mixer and cast into 150 × 150 × 150 mm steel moulds, covered with polythene sheet for 24 hours, the mould was then stripped and the cubes were placed in a temperature controlled curing tank at 20°C for a further 27 days prior to commencement of the compressive strength tests.

Batching took place within three hours from start to finish for all the cubes. The time of the year (August) ensured warm aggregates and the initial set was observed after 90 minutes. A full 28 days elapsed before the cubes were tested.

The following information was taken prior to commencement of the final compressive strength tests:

- all external dimensions; and
- saturated weight

The original concrete mix design used earlier is a relatively high strength concrete (45-50 N/mm^2) widely used for normal structural design in the built environment. Reduced compressive strength performance due to the addition of polypropylene fibres used in high strength concrete has been mentioned earlier (Aulia, 2002). The question of whether or not fibres reduce the strength using a less strong concrete has not been addressed and the revised design mix investigates this aspect of research.

The concrete mix design per m^3 was changed from that as used earlier in the research to – 245 kg of CEM 1, 1020 kg of washed coarse sand, 836 kg of washed natural 20 mm gravel, with 100 ml of RMC air entrainment per 50 kg of cement and variable fibre addition as applicable per batch, which was designed to achieve a lower design strength in the region of 18-25 N/mm^2.

The fibre type as used was 12 mm × 6.5 denier; monofilament extruded polypropylene fibre, quality assured to ISO 9001-2. The fibre as used was 7 mm shorter than one batch of the original research fibre and smaller in diameter, thus allowing a greater number of fibres per 0.9 kg addition per m^3 of concrete.

Slump tests were carried out at 0.55 water cement ratio to indicate the consistency limits; the recorded slump was 42 mm for batch 1 and 26 mm for batch 2.

Five sets of five cubes (25 No) were batched and mechanically vibrated in their moulds as shown in Table IV. The total weight of materials loaded into the mixer was between 90-135 kg thus allowing for a 30 per cent under capacity, and ensuring even mixing and dispersion of the fibres. It was noted from previous batching that when the mixer was fully loaded balling of the fibres took place and this was to be avoided.

From the results as obtained, there is an association between fibre volume/fraction addition and reduced compressive strength (see Figure 1).

Plain concrete showed the highest compressive strength, when compared to the cube strength of concrete with different polypropylene fibre doses. An overall average change in strength because of the use of polypropylene monofilament fibres of 20.4 per cent was discovered and is a significant change in the most widely used measurement (Compressive strength) to determine the quality of concrete. It should be noted that the normal combined fibre (structural/monofilament) commercial dosage per cubic metre of concrete used showed an 11.4 per cent reduction in compressive strength.

The results from the initial compressive tests were not conclusive due to the batch variation and small sample size. It was noted, as fibre volumes increase, there is a marked tendency for compressive strength to decrease. The density of concrete and polypropylene when compared show that, concrete has a bulk density of approximately 2400 kg/m^3, whereas polypropylene has a bulk density of 525 kg/m^3, (Finapro, 1998, p. 4) there is a density difference of 4.57 to one. The logic appertaining to this conclusion is that polypropylene is of a lower density and compressive strength than that of the surrounding concrete. Therefore it follows that; a significant volume fraction of polypropylene fibres within the test cubes has taken up volume with a low-density material, which must affect the final compressive strength of the concrete. The concrete as tested for a normal combined commercial dosage using structural and monofilament polypropylene fibres (6 and 0.9 kg/m^3) showed a significant reduction in compressive strength. A possible reason for the lower compressive strength was alluded to by Aulia (2002, p. 54), stating, "The fibres function as the initiator of the

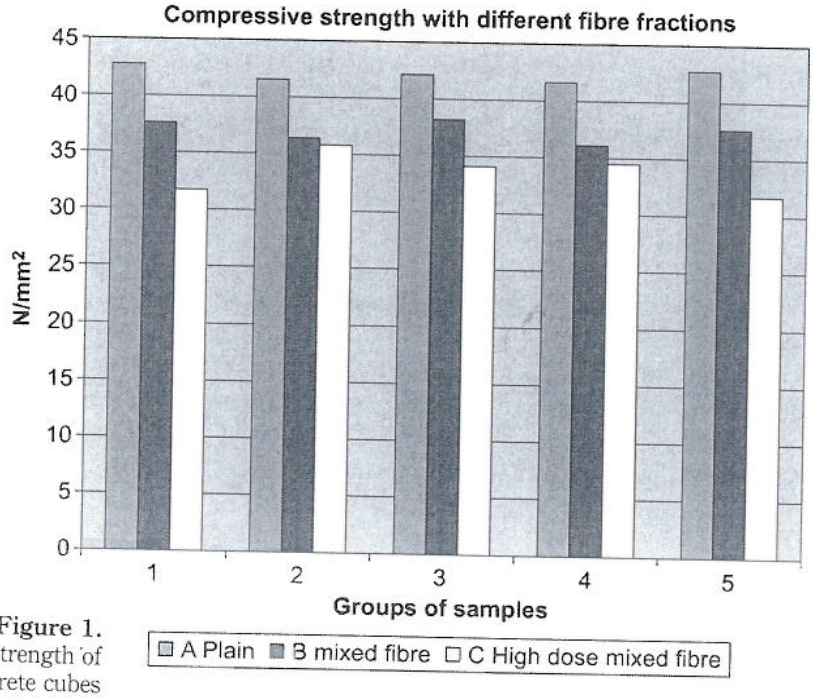

Figure 1.
Compressive strength of concrete cubes

Batching took place in two main mixes with concrete removed for individual mixes and remixed with fibre or air entrainment additives as applicable (Figure 2).

Variables to be tested are shown in Table IV: test specimen size was 150 mm × 150 mm × 150 mm and WCR 0.55. Cube reference, sizes and weight are shown in Table V.

Comparison of batch 1 and batch 2

Plain concrete (A) shows an average drop in compressive strength when compared against air entrained sample B of 3.55 N/mm^2. Low dose fibre concrete C when compared against normal dose D shows a drop in average compressive strength of 1.17 N/mm^2. The loss in compressive strength equates to 1.17 N/mm^2 per 0.45 kg/m^3 of monofilament fibres. There is a 1.35 kg/m^3 difference in dose between C and E and this is 3 × 1.17 N/mm^2 per 0.45 kg/m^3 which equals 3.51 N/mm^2 which is approximately the same as the reduction due to air entrainment and is an approximately proportional relationship between fibre dose and reduced compressive strength (see Figure 3).

The density and compressive strength difference between plain and air entrained concrete (batch 1) can be explained by the inclusion of air bubbles. There is a similar tendency with batch 2 which cannot be explained by the volume of concrete displaced by the polypropylene fibres. Gold (2000) states, "the intersections of fibres provide air bubbles and additional pressure relief chambers". However this may be an additionally important source of pressure relief relating to freeze/thaw protection whilst using fibres, as well as a reason for the decreasing compressive strength and decreasing density as shown in Figures 4 and 5. "Fibres actually entrain small amounts of air as a result of the surface treatment they receive in the manufacturing process" (Gold, 2000).

Table IV.
Concrete cube types

Reference	Sample	Number
A	1 Plain	5
B	1 Air entrained	5
C	1 Fibre 0.45 kg/m^3	5
D	1 Fibre 0.9 kg/m^3	5
E	1 Fibre 1.8 kg/m^3	5

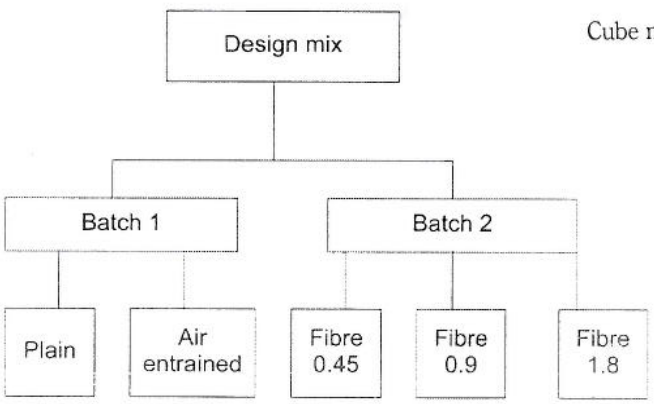

Figure 2.
Cube manufacture

Ref	Cube dimensions	Weight grams
A1	150 × 150 × 150	7,647
A2	150 × 150 × 150.5	7,769
A3	150 × 150 × 150	7,672
A4	150 × 150 × 150	7,636
A5	150 × 150 × 150	7,722
B1	150 × 150 × 149	7,405
B2	150 × 150 × 149	7,417
B3	150 × 150 × 150	7,420
B4	150 × 150 × 149	7,350
B5	150 × 150 × 150	7,382
C1	150 × 150 × 150	7,564
C2	150 × 150 × 150	7,647
C3	150 × 150 × 150	7,567
C4	150 × 150 × 151	7,626
C5	150 × 150 × 150	7,625
D1	150 × 150 × 150	7,574
D2	150 × 150 × 150	7,565
D3	150 × 150 × 150	7,514
D4	150 × 150 × 150	7,556
D5	150 × 150 × 150	7,593
E1	150 × 150 × 150	7,521
E2	150 × 150 × 150	7,435
E3	150 × 150 × 150	7,458
E4	150 × 150 × 150	7,457
E5	150 × 150 × 150	7,469

Table V.
Record of cube size and weight

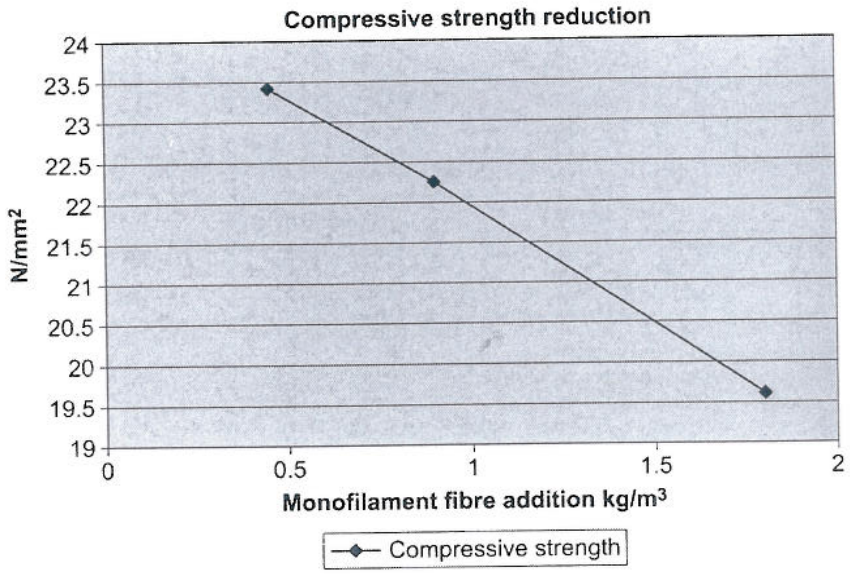

Figure 3.
Fibre dose related to compressive strength

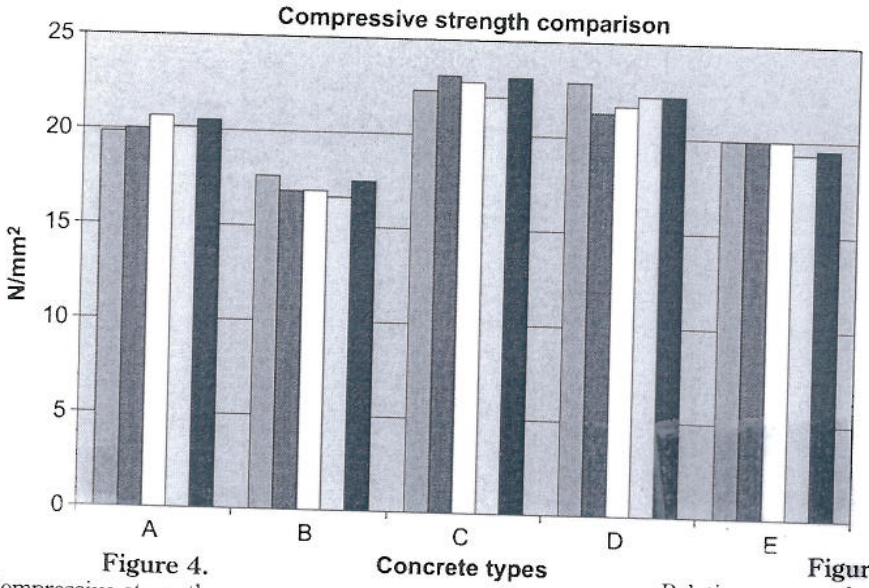

Figure 4. Compressive strength comparison of plain, air entrained and concrete with varying fibre dosage

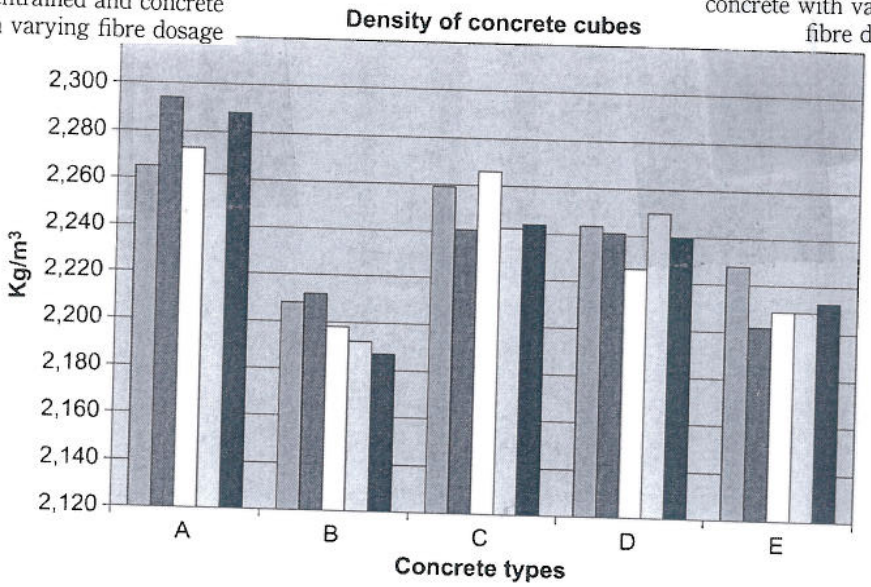

Figure 5. Relative average density of plain, air entrained and concrete with varying fibre dosage

This provides a reason for further investigation with regard to air entrainment from the use of fibres in concrete (see Tables VI and VII).

Water retention (low bleed) was thought to provide greater hydration of the cement, thus creating a larger volume of cement paste with subsequent evaporation pockets, leading to lower density. Further tests are required to corroborate this assumption.

The concrete as tested showed a small but significant reduction in compressive strength as well as small values of standard deviation from the mean, showing consistency of results within each batch.

Test 3. Medium/high strength concrete with monofilament fibre addition – density and final compressive strength

After examination of medium/high compressive strength concrete with mixed fibre additions and low/medium compressive strength concrete with a single monofilament fibre addition, a test was deemed necessary to compare a single commercially normal dose of monofilament fibres used in medium to high strength concrete and examine the effects of monofilament fibres with regard to density and compressive strength using a statistically significant sample size. The mix design was that as described previously for Test 1.

Aulia (2002) states, "With the use of many types of aggregate, the addition of polypropylene fibres in the concrete did not significantly affect the compressive strength and the modulus of elasticity of high strength concretes", however the concrete as used in this test was C70/85 using CEM 1 and various aggregates of differing engineering qualities.

The tests as described herein have used local aggregates of a similar nature, to aid direct comparison of results.

Density of plain concrete compared to fibre concrete is shown in Table VIII. The tests show a density difference of 1.9 per cent lower density for concrete with fibre

Cube ref.	A1	A2	A3	A4	A5	SD	Mean
Weight	7,647	7,769	7,672	7,636	7,722		7,682
Density	2,265	2,294	2,273	2,262	2,288		2,274.5
Comp. strength N/mm^2	19.86	20.04	20.68	20.13	20.52		20.73
						0.57	
Cube ref.	B1	B2	B3	B4	B5	SD	Mean
Weight	7,405	7,417	7,420	7,350	7,382		7,391
Density	2,208	2,212	2,198	2,192	2,187		2,197
Comp strength N/mm^2	17.64	16.86	16.88	16.55	17.45		17.18
						0.42	

Table VI.
Density, compressive strength standard deviation (SD) and mean values for Batch 1

Cube ref.	C1	C2	C3	C4	C5	SD	Mean
Weight	7,625	7,564	7,647	7,567	7,626		7,595
Density	2,259	2,241	2,266	2,242	2,244		2,248
Comp. strength N/mm^2	22.31	23.10	22.77	22.00	23.06		23.42
						0.88	
Cube ref.	D1	D2	D3	D4	D5	SD	Mean
Weight	7,574	7,565	7,514	7,593	7,556		7,556
Density	2,244	2,241	2,226	2,250	2,239		2,240
Comp. strength N/mm^2	22.88	21.28	21.65	22.20	22.23		22.25
						0.58	
Cube ref.	E1	E2	E3	E4	E5	SD	Mean
Weight	7,521	7,435	7,458	7,457	7,469		7,460
Density	2,228	2,202	2,209	2,209	2,213		2,210
Comp. strength N/mm^2	19.96	19.96	19.96	19.32	19.56		19.61
						0.30	

Table VII.
Density, compressive strength standard deviation (SD) and mean values for Batch 2

Sample reference	Plain concrete	Concrete with 0.9 kg/m^3 monofilament fibre addition
1	2,355.5	2,272.5
2	2,379.5	2,300.0
3	2,349.0	2,305.8
4	2,342.5	2,268.5
5	2,321.7	2,349.5
6	2,354.8	2,280.9
7	2,318.8	2,290.4
8	2,341.6	2,276.9
9	2,326.5	2,286.2
10	2,359.8	2,274.6
11	2,335.5	2,280.3
12	2,338.5	2,290.0
13	2,333.4	2,309.4
14	2,288.2	2,270.3
15	2,345.9	2,254.0
16	2,344.0	2,288.7
17	2,310.8	2,258.6
18	2,339.5	2,243.8
19	2,303.4	2,345.2
20	2,303.3	2,319.6
21	2,338.7	2,296.6
22	2,330.0	2,326.9
23	2,341.1	2,335.7
24	2,306.3	2,306.5
25	2,331.9	2,280.6
26	2,343.3	2,310.6
27	2,320.8	2,294.0
28	2,339.6	2,279.4
29	2,346.0	2,270.8
30	2,314.8	2,301.4
31	2,364.1	2,278.5
32	2,339.9	2,261.5
Mean density	2,334.64	2,290.86

Table VIII. Density of plain concrete compared to fibre concrete

inclusion. Clayton and Lennon (2000) found a significant reduction in density from the inclusion of polypropylene fibres due to the formation of voids. The results shown in Table VI show a 44 kg concrete density loss for fibre concrete, compared to a 0.9 kg addition of polypropylene fibres. The 49 to 1 reduction in mean density cannot be simply explained by the space occupied by 0.9 kg of fibres that produces the effect of reduction in density. It is argued that the voids must contain air and an air test on fresh concrete may prove this theory or rule out the effect of fibres entraining air into the concrete.

Compressive strength of plain concrete compared to fibre concrete is shown in Table IX.

When plain concrete was compared against fibre concrete there was a reduction in compressive strength of 4.27 N/mm^2, which equates to 8.7 per cent reduction between plain and concrete with fibre additions

The effects of fibres on final compressive strength appear to be reduced with regard to strength reduction when stronger concrete mixes are used.

Sample reference	Plain concrete N/mm^2	Concrete with 0.9 kg/m^3 monofilament fibre addition N/mm^2
1	48.9	43.35
2	49.75	45.75
3	51.88	43.2
4	47.38	44.38
5	50.25	43.38
6	50	45.87
7	48.38	46.38
8	47.75	47.13
9	47.63	46.4
10	49.13	44.5
11	49.63	42.1
12	50.25	45.13
13	47	44.88
14	48.63	46.13
15	47.13	46.63
16	48.13	46.13
17	50	44.25
18	50.5	42.38
19	49.75	45.88
20	48.5	46.13
21	47.38	44.38
22	50.13	45.5
23	48.13	42.50
24	49.75	43.87
25	48.38	44.9
26	46.5	45.13
27	48.63	42.88
28	48.9	44.5
29	48.88	42.88
30	49.88	42.78
31	47.13	42.38
32	48.88	44.88
Mean compressive strength	48.85	44.58

From fire tests on high-grade concrete, Clayton and Lennon (2000) state, "The effect on cube compressive strength . . . is approximately a 2 per cent reduction for each kg/m^3 of polypropylene fibres added". The observations taken from the author's test appear to suggest Clayton and Lennon's statement is correct in principle; indicating a trend towards smaller reductions in strength when using high-grade concrete with the addition of polypropylene fibres when compared to lower strength concrete with fibres (see Table X).

Test 4. Air entrainment/content tests in accordance with BS EN 12350-7 Clause 7, including plastic density and compressive strength

The reason for carrying out the air content test on fresh concrete was to see whether the reduction in density and compressive strength was due to air entrainment. The methodology was to compare a single concrete mix with and without admixtures to see if plastic density, air content and compressive strength were significantly changed. Mix design was as follows: aggregate (1,147 kg/m^3) type was marine dredged washed

Table IX.
Compressive strength of plain concrete compared to fibre concrete

gravel of an even grade and from a single source (Jarrow). The sand (654 kg/m^3) was pre blended also from a single supplier (Pallet Hill), Lafarge Dunbar supplied CEM 1 cement (300 kg/m^3). The WCR was planned at 0.61, monofilament polypropylene 12 mm × 6.5 denier fibre additions were used at a rate of 0.9 kg/m^3, air entrainment was by Cemex and used at a rate of 50 ml/50 kg of cement.

Concrete batching took place at 19.6 C using a paddle mixer for a total of 6 minutes mixing time per 0.025 m^3 batch. The mixer was sprayed with a very fine water spray prior to use and moisture content was taken of both sand and gravel (2.7 per cent and 8.9 per cent) prior to batching and adjustments were made to the added water during batching to ensure the water cement ratio was as close to 0.61 as possible. The aggregates were covered with visqueen sheeting between batch mixing to avoid evaporation and thus ensuring an accurate estimation of the WCR. The adjusted WCR for plain and air entrained concrete was 0.67 and 0.69 respectively, with both batches showing a slump of 40 mm measured to the nearest 10 mm with regard to consistency limits. Two 100 mm cubes were cast to test for compressive strength following 28 days immersion in a temperature controlled curing tank (see Table XI).

Results of air content, plastic density and compressive strength

The test results are shown below in Table IX. The plain mix as used in the test proved to be high strength concrete, which from earlier tests appears to slightly negate the effects of fibres in concrete with regard to final compressive strength. With regard to the air entrained concrete the strength reduction was within limits are defined by Klieger (1956) who stated, "For moderate strength concrete, each percentile of entrained air reduces the compressive strength by up to 9 per cent". The actual air content was 3.8 per cent × 9 per cent = 34.2 per cent and the final strength reduction proved to be 34 per cent. A second mixing of the fibre sample took place using 1.8 kg/m^3 of fibres and the air entrainment was

Table X. Percentage strength reduction compared to fibre content

Percentage strength reduction compared to plain concrete and fibre content			
Concrete strength	Normal single dose 0.9 kg/m^3	High dose (combined med/high) B High dose mono (E1-5)	High dose (combined) C
Low/medium	9.5	16.2 (E)	
Medium/high	8.7	11.4 (B)	20.4

Table XI. Air content, plastic density, strength reduction and compressive strength

Concrete type	Plain	Air entrained	Fibre 0.9 kg/m^3
Plastic density	2,420	2,344	2,411
Air content	1.4%	3.8%	1.4%
Final 28 day compressive strength N/mm^2	57.9 and 57.9	37.0 and 38.3	52.8 and 52.7
Manufacturing consistency – percentage density difference between samples	0	3.4	0.2
Percentage Strength reduction compared to plain concrete	0	34	8.9

measured at 1.6 per cent, being 0.2 per cent more air than the standard dose of 0.9 kg/m^3. The results were not considered significant.

Strength reduction (8.9 per cent) using fibres was similar to the third test (8.7 per cent) and a slightly lower value than achieved in test 2 (9.5 per cent). However the differences could be due to the small sample size, and the nature of variables in concrete manufacture, although the difference between the samples in terms of manufacturing consistency was very small.

Plain and fibre concrete showed no significant reduction in plastic density, which was different from the results achieved earlier with fully cured concrete; density was reduced when comparing plain and fibre concrete. The air content of the two batches, plain and fibre were identical at 1.4 per cent. Air entrained concrete showed an increased air content when compared to plain concrete of an additional 2.4 per cent and a subsequent plastic density reduction of 3.14 per cent, which compares very favourably with the earlier test (2) where a density reduction was observed at 3.4 per cent. The density reduction between the plain and fibre content was 0.37 per cent and cannot be considered significant.

The manufacturer of the air test apparatus was contacted (Rivers, 2005) to see if they knew of any reason why fibres would provide an inaccurate low reading and they confirmed fibres would not affect the air content reading of their apparatus. It was concluded that from the tests as carried out, fibres do not entrain air of any significant value into the concrete through their inclusion; however this does not explain the reduction in density through air entrainment or entrapped air. It may be that more water is retained due to the use of fibres in concrete and therefore more voids are formed once the concrete has dried out which affects the dry density and the plastic density would not be significantly affected, as water is included in the density calculation.

Conclusion

The reduction in compressive strength and density, between plain concrete and concrete with fibre additions, across the range of low/medium strength concrete and medium/high strength concrete, shows that polypropylene fibres when used as a concrete additive can affect a range of concrete strengths with regard to the lowering the compressive strength, when compared against the same plain concrete mix. The reduced compressive strength was thought to be caused by the inclusion of the fibres in the cement matrix of the concrete, which due to their low bond strength, (Richardson, 2005) form breaks in the CSH bond between the cement and the surrounding aggregate. The significance of the addition of monofilament polypropylene fibres into the cement is that approximately 30 million fibres per cubic metre will provide 30 million breaks in the bond between cement and aggregates and this inclusion represents a large surface area of material breaking the cement bond for a proportionally low weight inclusion. The reduced density could not be satisfactorily explained by the air content or the lower mass of the fibre addition. High water retention (low bleed) was observed during the slump tests and this was thought to provide greater hydration of the cement, thus creating a larger volume of cement paste with subsequent evaporation pockets, leading to lower density. An explanation for the observed reduced density may be that, "Fibres contributed to the problems of compacting . . .hence the reduced density" (Clark, 2006).

When specifying concrete with fibre inclusion, the manufacturer should amend the design mix to ensure compressive strength is maintained.

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Further reading

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Corresponding author

Alan E. Richardson can be contacted at: alan.richardson@unn.ac.uk