Available online at www.sciencedirect.com
ScienceDirect
Cement & Concrete Composites 28 (2006) 811–816
Cement & Concrete Composites
www.elsevier.com/locate/cemconcomp

Effects of steel fibers and mineral filler on the water-tightness of concrete pipes

Tefaruk Haktanir [a,*], Kamuran Ari [a], Fatih Altun [a], Cengiz D. Atis [b], Okan Karahan [b]

[a] *Erciyes University, Engineering Faculty, Civil Engineering Department, Kayseri 38039, Turkey*
[b] *Çukurova University, Engineering Faculty, Civil Engineering Department, Adana, Turkey*

Received 9 March 2006; received in revised form 6 June 2006; accepted 9 June 2006
Available online 8 August 2006

Abstract

Water-tightness of concrete and reinforced concrete pipes used to convey sewage flow of any kind is extremely important from the aspects of (1) groundwater contamination and (2) durability of the pipes. In this study, water-tightness tests were applied on plain concrete, reinforced concrete, and steel fiber concrete pipes of 500 mm diameter. Standard seepage tests were applied on many pipes of various materials and combinations with the objective of determining the pipes with the best water-tightness. Tests on plain concrete pipes whose concrete included finely ground limestone passing the no. 100 sieve ($d < 0.15$ mm) at an amount of 7% by dry weight of the total aggregates revealed that the water-tightness of former was 57% better than that of pipes manufactured without the filler. The water-tightness values measured on steel fiber concrete pipes with a fiber dosage of 25 kg/m^3 turned out to be 47% and 15% better than those of plain concrete pipes and reinforced concrete pipes, respectively. Those findings tangibly reveal that the addition of steel fibers and mineral filler in concrete pipes improve their seepage property.

Keywords: Concrete; Concrete pipes; Steel fibers; Water-tightness; Mineral filler

1. Introduction

Some chemical substances present in municipal or industrial sewage waters can be mechanically detrimental to the pipe material and may reduce their physical and service lives. If either the conveyed water inside the pipe or the ambient groundwater in contact with the pipe seeping into the concrete causes chemical reactions such as conversion of $Ca(OH)_2$ to gypsum and formation of sulphoaluminate salts, this may result in deterioration of concrete and formation of cracks which would further escalate the chemical attacks. Seepage of the sewage waters out of a sewer pipe has hazardous effects to the soil and groundwater. Therefore, water-tightness of sewage pipes is utterly important.

Concrete and reinforced concrete pipes have been used widely for conveyance of storm waters and sewage waters as open channels, and even for municipal or irrigation waters as low-head pressure conduits. In recent times, steel fiber concrete (SFC) has found many applications such as tunnel linings, factory floors, and concrete pipes. Now it is a known fact that tensile strength, ductility, toughness (energy absorption capacity), and durability of concrete are appreciably improved by addition of steel fibers, and there are standards on steel fiber concrete in general [1,2] and about steel fiber concrete pipe, in particular [3,4].

In a recent study, improvement of water-tightness of concrete pipes was aimed by addition of cellulose fibers into the concrete [5]. Usage of pozzolan-blended Portland cements in hydraulic structures is long known to improve concrete durability, and the effect on strength and water-tightness by partial replacement of Portland cement by fly ash during pipe production has been reported [6].

* Corresponding author. Tel.: +90 352 4370080; fax: +90 352 4375784.
E-mail addresses: thaktan@erciyes.edu.tr (T. Haktanir), cengiz@cukurova.edu.tr (C.D. Atis).

0958-9465/$ - see front matter
doi:10.1016/j.cemconcomp.2006.06.002

Studies have also indicated that the inclusion of mineral fillers passing the no. 100 sieve ($d < 0.15$ mm), like finely-ground limestone, at reasonable amounts, improves many mechanical and physical properties of concrete, because this mixture provides a more compact concrete with less voids [6,7]. Limestone filler is readily available as a by-product during the crushing process of large limestone boulders quarried for crushed aggregate production. Limestone filler passes all the separator sieves and accumulates at the bottom of the separator unit of the crushed aggregate plant. It could directly be obtained by grinding of crushed limestone sand, also, which does not necessitate too much grinding energy because crystallized calcareous limestone is not too hard a mineral. The study by Topcu and Ugurlu particularly recommends that a limestone filler of about 7%–10% by weight of total aggregates is optimum because it increases both compressive and flexural strengths of concrete and it also improves water-tightness [7]. They report that increasing the mineral filler above 10% adversely affects the mechanical and physical properties of concrete because of the necessarily increased amount of mix water [7]. Hence, the objective of this study has been to perform experiments to determine the effects of (1) steel fiber dosage and (2) ground limestone filler addition to the mixed aggregates during pipe production on water-tightness of steel fiber concrete pipes in a comparative way by performing the same tests on conventional concrete and reinforced concrete pipes.

In a recent study by Justness [8], it is reported that 'Mortars with 20% limestone filler by weight of cement subjected to 5% sodium sulfate solution with excess gypsum (solution saturated with gypsum) at 5 °C form excessive thaumasite in the binder within 10 months exposure with resulting mass loss, expansion and strength retrogression'. According to the study by Justness, a strong sulfate–water environment saturated with gypsum, in the long-term, may give rise to the expansive thaumasite formation in concrete having limestone filler [8]. The long term effect of limestone filler in intense sulfate environment is out of the scope of this study. The presence of mineral filler of the sizes passing the no. 100 sieve on the water-tightness of concrete pipes is investigated. Accordingly, seepage tests were carried out on prototype pipes in 28-days after their production.

2. Experimental studies

All the pipes needed for the tests were produced by a concrete pipe manufacturing plant having an official certification by the Turkish Standards Institute.

2.1. Aggregates and Portland cement for concrete

Firstly, standard sieving, specific gravity, and absorption tests were performed on three randomly taken samples of four different groups of aggregates regularly used for concrete pipe manufacture. All the relevant tests were carried out in accordance with the pertinent Turkish Standards, which are actually very similar to either EN, DIN, or ASTM, or ACI standards. The newest Turkish Standard about aggregates for concrete (TS-706-EN-12620) is actually a direct Turkish translation of the relevant EN standard [9]. The same is valid for the standard about concrete pipes, and therefore, overtly, the pertinent Turkish Standard is expressed as TS-821-EN-1916 [3]. The sieves for gradation of aggregates and the tests are the same as those of DIN-1045 [10] and other German Standards, which are 0.25, 0.5, 1, 2, 4, 8, 16, 32, 63 mm square opening sieves, which are different from those of ASTM C33 [11].

The pipe manufacturing plant regularly used a natural sand and three different-gradation crushed aggregate groups, which were classified as 0–7 mm natural sand, 0–6 mm crushed sand, 6–10 mm crushed medium, and 10–16 mm crushed coarse. Additionally, sufficient amount of finely-ground limestone filler passing the no. 100 ASTM-C33 [11] sieve ($d < 0.15$ mm) was obtained by special order to be used later for some concrete pipes. By standard tests, the average bulk specific gravities and absorptions of these four groups of aggregates and the filler were determined to be in 2.65–2.73 and 1.10%–2.26%, respectively, which are within common ranges.

PC-42.5 type of Portland cement was used in production of the pipes tested, whose standard and commercial symbol according to both the pertinent European and Turkish standard is: CEM-I-42.5R [12]. Its bulk specific gravity as reported by the manufacturer was 3.08. CEM-I-42.5R is a pure Portland cement without any pozzolan admixtures, and its 2-day, 7-day, and 28-day compressive strengths by Rilem–Cembureau test are 23, 35, and 50 N/mm^2, respectively. As mentioned already, most of the recent Turkish Standards are direct translations of the pertinent ENs, and the cement standard is one of these, TS-EN-197-1 [12].

2.2. Mix recipe and steel fibers

The EN and Turkish Standard about concrete, reinforced concrete, and steel fiber concrete pipes, TS-821-EN-1916, dictates that the concrete used in reinforced concrete pipe production be a concrete class of C35 or higher [3]. A similar German Standard, DIN-EN-641, which is also an EN Standard, states: 'The minimum 28-day compressive strength of the concrete shall be 35 MPa' [13]. Previous crushing tests on 150×300 mm cylindrical specimens, workability tests for pipes with the strong-vibration capability of mould platforms of the plant, and experience in pipe production resulted in the mix design for a zero-slump concrete whose recipe is given in Table 1. No admixtures, like plasticizers or such, are used, and the fresh concrete looks rather dry and stiff and even it has the appearance of an over-saturated aggregate to the novice eye.

Two sizes of steel fibers of Dramix RC80/60-BN and ZP-308 types of Bekaert were used. The total length and cross-sectional diameter of RC80/60-BN and ZP-308 were 60 mm and 0.75 mm, and 30 mm and 0.75 mm,

Table 1
Mix proportions of the C35 class of concrete with and without the limestone filler

Type of ingredient	Plain concrete, amounts (kg/m^3)	Concrete with limestone filler, amounts (kg/m^3)
Portland cement, PC-42.5	350	350
Mix water	117	123
Limestone filler (SSD)[a]	–	141
0–7 River sand (SSD)	710	562
0–6 Crushed sand (SSD)	604	599
6–10 Crushed medium (SSD)	301	299
10–16 Crushed coarse (SSD)	401	398

[a] SSD means 'in "saturated surface-dry" condition'.

respectively. The yield strength of these steel fibers was 1050 N/mm^2, and their properties complied with the relevant Turkish Standard, also [14].

3. Preliminary tests

In order to keep the total number of experimental combinations at a reasonable and manageable amount, it was decided that only two different fiber dosages of 25 kg/m^3 and 40 kg/m^3 were to be applied for steel fiber concrete pipes. Coincidentally, in a relevant technical report, the fiber dosages of 25 kg/m^3 and 40 kg/m^3 are presented [15].

Pipe of 500 mm is widely manufactured both as plain concrete and reinforced concrete pipes depending on purpose of usage, and this size was used in these tests.

The concrete batch of sufficient volume, whose mix proportions have been consistently the same as in Table 1, was poured into steel moulds resting on a vibrating platform. The vibration is applied to the steel mould until the fresh concrete completely settles in and no more fresh concrete can be placed into the mould.

Three cylindrical samples of 150 × 300 mm dimensions out of each different type of concrete used in pipe production were taken. At the end of 28 days of curing in water at 21 °C, the stress–strain peculiarities of all these cylindrical samples were obtained by standard tests. Fig. 1 shows

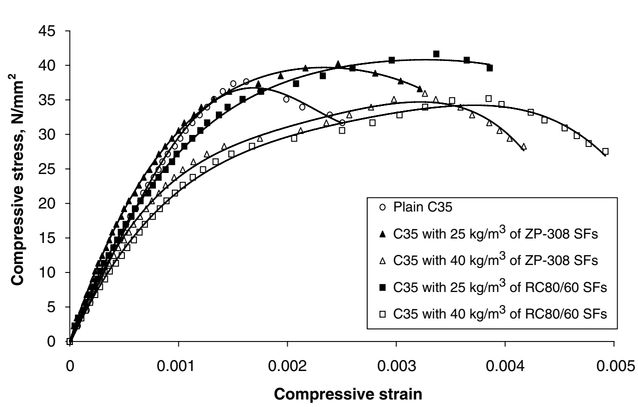

Fig. 1. Stress–strain diagrams of different concrete specimens under compression.

Table 2
Mean values of mechanical properties of the C35 class of concretes with and without steel fibers measured on three 150 × 300 mm cylindrical samples of each group

Type of concrete	Mean ultimate load (kN)	Mean compressive strength (N/mm^2)	Mean secant modulus of elasticity (kN/mm^2)
C35, plain	665	37.6	32.0
C35 with 25 kg/m^3 of ZP-308	711	40.2	33.3
C35 with 40 kg/m^3 of ZP-308	630	35.6	29.6
C35 with 25 kg/m^3 of RC80/60-BN	736	41.6	30.8
C35 with 40 kg/m^3 of RC80/60-BN	624	35.3	25.8

the average stress–strain curves and Table 2 reports the average findings. The compressive strength of steel fiber concrete with a fiber dosage of 25 kg/m^3 is 10% greater than the plain concrete and their secant moduli of elasticity are not too different from each other.

4. Production of pipes and three-edge-bearing tests

C35 type of concrete and S-420 type of indented steel bars whose yield strength was 420 N/mm^2 were used for all the pipes. The different combinations of the pipes produced, whose wall thickness was 65 mm for all, were as listed below:

(i) Plain concrete pipes (CP).
(ii) Plain concrete pipes in whose concrete mineral filler was added (FACP).
(iii) Reinforced-concrete pipes (RCP).
There was only one elliptical reinforcement which was 7 mm bars placed at 75 mm intervals, ∅7/75, which amounts to 5.1 cm^2 of circumferential reinforcement per 1 m of pipe length. The longitudinal reinforcement used was 5 mm bars placed at 200 mm circumferential intervals, ∅5/200. The reinforced concrete pipe used in this study was somewhere close to class IV of ASTM-C76 [16], and hence it was a strong reinforced-concrete pipe.
(iv) Pipes with ZP-308 type steel fibers at a dosage of 25 kg/m^3 (SFCP-ZP-308-25).
(v) Pipes with ZP-308 type steel fibers at a dosage of 40 kg/m^3 (SFCP-ZP-308-40).
(vi) Pipes with RC80/60-BN type steel fibers at a dosage of 25 kg/m^3 (SFCP-80/60-25).
(vii) Pipes with RC80/60-BN type steel fibers at a dosage of 40 kg/m^3 (SFCP-80/60-40).

After vibration, the steel mould is removed out of the freshly cast pipe, and the pipe rests at room temperature in the plant for 6 h. The first curing phase is increasing the ambient temperature at a rate of 12 °C/h. The second phase is application of steam curing at the constant temperature of 60 °C for a period of 12 h, and the third phase is cooling back to the room temperature again at the rate of 12 °C/h.

According to a relevant report by the Institut für Bautechnik, the ultimate crushing strength for steel fiber concrete pipes with a fiber dosage of 25 kg/m^3 must be greater than 60 kN/m for pipes of internal diameter of 500 mm and wall thickness of a minimum of 60 mm [15]. The crushing test, which is termed as 'three-edge-bearing test' in relevant standards [3,17], was performed on all the pipes as shown in Fig. 2. The loading lath on top and two support laths at the bottom extended throughout the total length of each pipe including their bell (or groove) parts except for their spigot (or tongue) portion at the end as specified in these standards. The top and bottom laths had special profiles perfectly matching the profile of the bell portion, and plaster of Paris was applied between the laths and the pipe as required in TS-EN-821 [3] (see Fig. 2(a) and (b)). The steel fiber concrete pipes produced with the RC80/60-BN type of fibers at a dosage of 25 kg/m^3 produced in this study had an ultimate strength of 78 kN/m and therefore comfortably satisfied this German requirement. These SFCP-80/60-25 class pipes satisfied even the highest class, class H, of the British Standard: BS-DD-76-Part-2, also, because 78 kN/m is greater than 58 kN/m, the lower limit for class H pipes of 525 mm internal diameter [4]. According to the Turkish (and European) Standard TS-821-EN-1916 [3] the lower acceptable limit for the three-edge-bearing strength for a plain concrete pipe of 500 mm internal diameter is 35 kN/m, which is the same as that in ASTM-C14 for 'class 1' concrete pipe [18]. The plain concrete pipes in this study had an average three-edge-bearing strength of 43 kN/m. The same strength for the limestone filler added concrete pipe was 48 kN/m, which satisfies even the 'class 2' type according to ASTM-C14 [18]. A summary of the three-edge-bearing tests on all the concrete pipes with and without steel fibers

Fig. 2. (a) Three-edge-bearing test applied on one of the pipes. (b) The crack formation of a steel fiber concrete pipe under three-edge loading.

Table 3
Summary of the three-edge-bearing tests on all the concrete pipes, reinforced concrete pipes, and steel fiber concrete pipes

Types of pipe	Ultimate load for each pipe			Mean ultimate load (kN)	Mean ultimate load per meter length of pipe (kN/m)	Relative difference w.r.t. RCP (%)	Acceptable lowest ultimate load per meter length of pipe as stipulated in TS-821-EN-1916 (kN/m)	Mean cost of a single pipe (US $)
	Pipe no. 1 (kN)	Pipe no. 2 (kN)	Pipe no. 3 (kN)					
CP	65.0	64.0	64.5	64.5	43.0	–	35	31
FACP	72.0	71.0	73.0	72.0	48.0	–	35	33
RCP	111.1	110.3	110.4	110.6	73.7	–	67.5	54
SFCP-ZP-308-25	104.9	105.8	105.2	105.3	70.2	−5	67.5	46
SFCP-ZP-308-40	113.0	111.8	112.1	112.3	74.9	+2	67.5	52
SFCP-80/60-25	118.0	117.2	117.0	117.4	78.3	+6	67.5	46
SFCP-80/60-40	121.0	121.3	120.1	120.8	80.5	+9	67.5	52

is presented in Table 3. The length of all the pipes tested in this study was 1.5 m (=1500 mm). On the sixth and eighth columns of Table 3, the measured ultimate loads per meter length of the pipes and the acceptable lower limit values as specified in TS-821-EN-1916 [3], respectively, are given for comparative purposes. The actual strength must be greater than the lower limit specified in the standard in order for any pipe to be used in actual applications.

Steel bars of suitable diameters used in conventional reinforced concrete pipes are transported to the plant and stored in it. They are cut in needed lengths, bent in special machinery in correct dimensions, and the most time consuming is the point welding at intersections of circumferential and longitudinal bars of the reinforcement caging. Hence, preparation of the reinforcement cage of each pipe is both time consuming and costly. Addition of steel fibers directly into the fresh concrete batch during mixing as if another ingredient is much simpler, much less time consuming, and much less labor-intensive.

5. Water-tightness tests

This test was performed in accordance with TS-821-EN-1916 [3]. Both ends of a pipe are insulated firmly by standard rubber sheets squeezed between the steel plate and the end of the pipe, the strong squeezing force being applied by tightly screwed four steel bars extending all

Fig. 3. Water-tightness experiment applied to one of the pipes.

Table 4
Amounts of water added during water-tightness tests in accordance with TS-821-EN-1916 on all the concrete pipes with and without steel fibers and relative differences of seepage losses

Type of pipe	Water loss from each pipe			Average water loss (cm^3)	Relative drop w.r.t. CP (%)	Relative drop w.r.t. RCP (%)
	Pipe no. 1 (cm^3)	Pipe no. 2 (cm^3)	Pipe no. 3 (cm^3)			
CP	100	130	120	117	–	–
FACP	55	50	45	50	57	31
RCP	70	80	70	73	38	–
SFCP-ZP-308-25	70	75	65	70	40	4
SFCP-ZP-308-40	65	65	70	67	43	8
SFCP-80/60-25	65	60	60	62	47	15
SFCP-80/60-40	60	55	60	58	50	20

the way between the two ends of the pipe. With the help of a high-pressure hose, a standard relative pressure of 0.5 Bar (≈5 m water column) is exerted by a compressor. Initially, the inside of the pipe is completely filled up with water at the constant pressure of 0.5 Bar. Five minutes later, any missing water is replenished to make sure that the test will be performed with a completely full pipe. Next, the constant pressure of 0.5 Bar is applied for a period of 15 min. The pressure is released at the end of this 15 min period, and the loss of water from inside the pipe is complemented by addition of extra water, whose volume is considered as water amount that is lost by seepage through the walls of the pipe. The permeability or porosity of the pipe material will be directly reflected by the amount of water lost out of the completely sealed pipe under this constant relative pressure of 0.5 Bar. Fig. 3 shows the instant of this test applied on one of the pipes. Table 4 presents the seepage losses by this standard test of TS-821-EN-1916.

Similar tests are specified in DIN-EN-641 [13] and ASTM-C-497 M [17]. In Section 4.2 of DIN-EN-641 an internal hydrostatic pressure test is required during which an inside pressure of either maximum design pressure +1200 kPa or 1.2 times the maximum design pressure, whichever is greater, is applied. The pipe is restrained within a hydrostatic test rig and pressure tested for a period of 5 min. During the test the pipe shall be absolutely watertight and show no leaks [13]. In Section 8 of ASTM-C-497M a similar 'hydrostatic test method' is described [17].

6. Discussion and conclusions

Investigation of the results of the standard tests applied on various concrete pipes leads to the following conclusions:

(1) The optimum steel fibers dosage should be around 25 kg/m^3, because an increase of fiber dosage from 25 kg/m^3 up to 40 kg/m^3 brings about negligibly small improvements in water-tightness for a considerably great 60% increase in the mass of steel fibers used. The longer RC80/60-BN type of steel fibers was slightly more efficient for steel fiber concrete pipes than the shorter ZP-308 type.
(2) The water-tightness of steel fiber concrete pipes with a steel fiber dosage of 25 kg/m^3 is found to be 15% better than that of conventional reinforced concrete pipes. The reason for this improvement is most probably due to the reduced internal cracking on account of the presence of the steel fibers in the concrete.
(3) Addition of fine limestone filler passing the no. 100 sieve ($d < 0.15$ mm) to concrete at about 7% by dry weight of total aggregates is found to improve the water-tightness around 57% as compared to plain concrete pipes without filler. Therefore, addition of mineral filler at 7% by weight to pipe concrete seems to cause a considerable improvement in leakage property of the concrete pipes. As pointed out by a recent study [8], limestone filler may make the concrete vulnerable to sulfate attack in the long term if the pipes are in a strong sulfate environment. Therefore, usage of limestone powder as mineral filler in strongly sulfate-prone environments should be considered cautiously from that aspect, and ground volcanic tuff or any natural pozzolan could be chosen instead of limestone for strong sulfate environments.

References

[1] ACI 544.4R-88. Design considerations for steel fiber reinforced concrete. American Concrete Institute, ACI Committee 544, 1988 (Reapproved 1999).
[2] TS-10514. Concrete – steel fiber reinforced – Rules for mixing concrete and control. Turkish Standards Institute, Necatibey Caddesi, 112, Ankara, Turkey, 1992.
[3] TS-821-EN-1916 Concrete pipes and fittings, Unreinforced, Steel Fiber, and Reinforced. Turkish Standards Institute, Necatibey Caddesi, 112, Ankara, Turkey, 1998.
[4] BS-DD-76-Part-2. Draft for development, precast concrete pipes of composite construction. British Standards Institution, 1983.
[5] Fisher AK, Bullen F, Beal D. The durability of cellulose fibre reinforced concrete pipes in sewage applications. Cement Concrete Res 2001;31:543–53.
[6] Berryman C, Zhu J, Jensen W, Tadros M. High-percentage replacement of cement with fly ash for reinforced concrete pipe. Cement Concrete Res 2005;35(6):1088–91.
[7] Topcu IB, Ugurlu A. Effect of the use of mineral filler on the properties of concrete. Cement Concrete Res 2003;33:1071–5.
[8] Justness H. Thaumasite formed by sulfate attack on mortar with limestone filler. Cement Concrete Compos 2003;25:955–9.
[9] TS-706-EN-12620. Aggregates for concrete. Turkish Standards Institute, Necatibey Caddesi, 112, Ankara, Turkey, 2002.
[10] DIN-1045 Concrete and reinforced concrete, design and construction. Deutsches Institut für Normung, E.V., Beuth Verlag, GMBH, Berlin, 1985.
[11] ASTM C-33-03. Standard specification for concrete aggregates. American Society for Testing and Materials, 2003.
[12] TS-EN-197-1. Cements – Part 1: Compositions and conformity criteria for common cements. Turkish Standards Institute, Necatibey Caddesi, 112, Ankara, Turkey, 2004.
[13] DIN-EN-641. Reinforced concrete pressure pipes, cylinder type, including joints and fittings (English version of DIN-EN-641). European Committee for Standardization, Central Secretariat, rue de Strassart 36, B-1050, Brussels, 1994.
[14] TS-10513. Steel fibers for concrete reinforcement. Turkish Standards Institute, Necatibey Caddesi, 112, Ankara, Turkey, 1992.
[15] Institut für Bautechnik, Rohre aus Stahlfaserbeton (Steel–fiber–concrete pipe), Zulassungsbescheid. Institut für Bautechnik, Anstalt des öffentlichen Rechts, 1988.
[16] ASTM-C76M – 03. Standard specification for reinforced concrete culvert, storm drain, and sewer pipe (Metric). American Society for Testing and Materials, ASTM; 2003.
[17] ASTM-C497M – 97. Standard test methods for concrete pipe, manhole sections, or tile (Metric). American Society for Testing and Materials, ASTM; 1997.
[18] ASTM-C14M – 04. Standard specification for concrete sewer, storm drain, and culvert pipe (Metric). American Society for Testing and Materials, ASTM; 2004.