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An investigation of concrete pipes under loading

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Abstract

Three-edge-bearing and crack size measurement tests, along with tension testing, were performed on concrete pipes of 500 mm diameter, which included plain concrete, reinforced concrete, and steel-fibre concrete variants. The experimental procedure included a specific test on an elliptical reinforced concrete pipe subjected to tension. Various simulation models were used to validate these experimental findings. The data showed that the steel-fibre concrete pipes, incorporating RC80/60-BN type steel fibres at a dosage of 25 kg/m^3, exhibited a three-edge-bearing strength that was 82% higher than that of plain concrete pipes and 6% higher than that of reinforced-concrete pipes. Moreover, the average crack size in the steel-fibre pipes was found to be 47% smaller than that of plain concrete pipes and 15% smaller compared to reinforced-concrete pipes. Further examination of steel-fibre concrete pipes with a steel fibre dosage of 40 kg/m^3 indicated that a 60% increase in fibre content led to only marginal enhancements, implying that a fibre dosage of 25 kg/m^3 may be close to the optimum. Overall, the tests validate that steel-fibre concrete pipes are more cost-effective and possess enhanced mechanical and physical attributes relative to reinforced-concrete pipes.

Keywords: Concrete pipes; Reinforced-concrete pipes; Steel-fibre concrete pipes; Three-edge-bearing strength; Crack characteristics

1. Introduction and literature review

Concrete and reinforced-concrete pipes have been in widespread use for conveyance of storm water and sewage water as open channels, and even for municipal or irrigation water as low-head pressure conduits since late 1800s. In recent decades, steel-fibre concrete has found many applications such as tunnel linings, factory floors, and concrete pipes. Now it is a known fact that the tensile strength, ductility, toughness (energy absorption capacity), and durability of concrete are appreciably improved by addition of steel fibres (e.g. [1–4]), and there are standards about steel-fibre concrete in general [4,5] and about steelfibre concrete pipe, in particular [6].

Manufacturing of the cage form of the conventional reinforcement bars adjusted for concrete pipes requires special bending, welding, and placement machinery, and it is time-consuming. Steel fibres of standard sizes, on the other hand, can be added to the pan-mixer of any concrete plant as if they were another aggregate or mineral admixture. Without any extra process modification, steel-fibre concrete can be produced and cast in the moulds similar to the ordinary plain concrete. Therefore, steel-fibre concrete pipes seem to be an economical alternative to the classically-reinforced-concrete pipes. Browsing through relevant literature, it seems that a steel fibres dosage of about 30 kg/ m^3 is close to optimum [4–8].

The objective of this study has been to perform experiments to determine the effect of dosage of steel fibres on pipe strength and cracking peculiarities of steel-fibre concrete pipes in a comparative way by performing the same tests both on conventional reinforced-concrete pipes and on steel-fibre concrete pipes.

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2. Experimental studies

A mutual agreement between the Civil Engineering Department of Erciyes University and a concrete pipe manufacturing plant having official certification by Turkish

Standards Institute was reached. The plant would produce all the necessary pipes of various peculiarities at sufficient numbers, and all the research findings would be supplied to the plant in return.

The plant regularly uses a natural sand group and three different-gradation crushed aggregates, whose maximum grain size is 16 mm, and all the four groups possess favourable properties of specific gravities and gradations to yield even high-strength concrete.

PC-42.5 type of Portland cement is used, which is CEMI-42.5R according to both the recent relevant Turkish and also the European Standard [9]. This 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. CEM-I42.5R is a cement having a little higher strength than Type I of ASTM C150 [10].

The Turkish Standard TS-821-EN-1916, which is a verbatim translation of the pertinent European Standard EN1916, dictates that the concrete used in reinforced-concrete pipe production of a C35 class or higher [6]. 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 an appearance like an over-saturated aggregate to the novice eye. S-420 type of indented steel bars are used, whose average yield strength is 420 N/mm^2.

2.1. Preliminary tests

From previous studies, a steel fibres dosage of about 30 kg/m^3 seemed to be a reasonable value for normal structural

Table 1

Mix Recipe of C35 class of concrete used in producing all the pipes tested

Type of ingredient	Amount (kg/m^3)
Portland cement, CEM-I-42.5R	350
Mix water	117
0–7 River sand (SSD)	710
0–6 Crushed sand (SSD)	604

oncrete [7,8]. In a relevant technical report, the steel fibres dosages of 25 kg/m^3 and 40 kg/m^3 are presented [12]. It is stated in Section 7.2 of BS-DD-76-Part-2, that: “when tested as described in appendix B, the fibre content of each sample taken from the mix should be not less than 25 kg/m^3” [13]. Having been influenced by these publications and in order to keep the total number of experimental combinations at a reasonable and manageable amount, it was decided that only two different steel fibres dosages of 25 kg/m^3 and 40 kg/m^3 were to be applied for steel-fibre concrete pipes.

Among other sizes of pipes, either concrete pipes or reinforced-concrete pipes of 500 mm inner diameters have been manufactured by the concrete plant upon orders from mainly the municipalities. The concrete pipes used vary in sizes from 200 mm up to 3000 mm. 500 mm pipe is widely manufactured both as plain concrete pipe and reinforced-concrete pipe depending on purpose of usage. The weight of 500 mm pipe is about 500 kg, which is easily manageable by the personnel of the materials laboratory of this study. Altogether, 7 · 5 = 35 numbers of pipes of various compositions were tested. The work load for their transportation from the plant to the campus, and for carrying away and disposing the debris of the crushed pipes was just manageable for 500 mm pipes, also. For these practical reasons, the 500 mm pipe size was chosen for this study.

The concrete batch of sufficient volume, whose mix proportions have been consistently the same as in Table 1, is poured into the steel mould of any such pipe, which rests on a strongly 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.

A vibrating table to which three cylindrical moulds of 150 · 300 mm dimensions can be firmly mounted was placed close-by to the pipe concreting platform, and all the three moulds were filled in with the same concrete as that used in pipe production. The vibrating table was operated until the cylindrical specimens could not take any more concrete, a practice similar to the filling of prototype pipe moulds.

In the conducted study, an elliptical reinforced concrete pipe with a minor and major diameters are 70 x98 mm was subjected to tension testing. The pipe, with a length of 1 meter, and shell thickness 3mm underwent initial testing under a load of 5 kN. The mechanical properties of the concrete and steel used in the construction of the pipe are detailed in Table 2. During testing, the pipe displayed a tension stress of 3.8 kPa with a resultant displacement measuring 1.7 mm. These experimental results provide insight into the behavior of the elliptical reinforced concrete pipe under load.

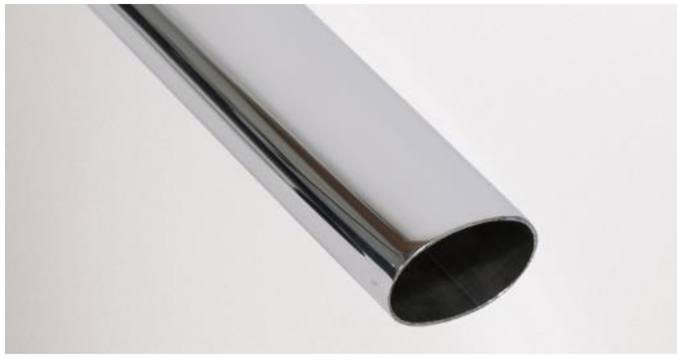

Fig. 1. Steel pipe 70*98 mm.

Table 2 : Mechanical properties of the steel and concrete under testing

a) steel

Stress (MPa))	Strain
200	0
240	0.0235
280	0.0474
340	0.0935
380	0.1377
400	0.18
200	0
240	0.0235
280	0.0474
340	0.0935
380	0.1377
400	0.18

b) concrate

Stress (MPa)	Strain
24.019	0
29.208	0.0004
31.709	0.0008
32.358	0.0012
31.768	0.0016
30.379	0.002
28.507	0.0024
21.907	0.0036
14.897	0.005
2.953	0.01

Specimens from the plain C35 concrete batch, and from four different C35 batches, two with RC60/80-BN types of steel fibres and two with ZP308 types, were all subjected to these compresso-meter experiments. It is interesting that, the compressive strength of steel-fibre concrete with a steel fibres dosage of 25 kg/m^3 is10% greater than the plain concrete and their secant modulus of elasticity do not deviate from each other.

Pipes with steel fibres of RC80/60-BN type at a dosage of 40 kg/m^3. In Tables 3 and 4, the abbreviation: SFCP-80/60-40 is used for this type of pipes, chosen as the acronym for 'steel-fibre concrete pipe produced with fibres of RC80/60-BN type at a dosage of 40 kg/m^3'.

Table 3

Summary of the three-edge-bearing tests on all the concrete pipes with and without steel fibres

Type of Pipe	Testing load (kN)	Average ultimate load per meter length of pipe (kN/m)	Relative difference with respect to RCP (%)	Lower limit for ultimate load per meter of pipe in Table 3a of TS-821-EN-1916 (kN/m)
Elliptical (initial testing)	5	43.0	–	35
RCP	110.6	73.7	–	67.5
SFCP-ZP-25	105.3	70.2	5	67.5
SFCP-ZP-40	112.3	74.9	+2	67.5
SFCP-80/60–25	117.4	78.3	+6	67.5
SFCP-80/60–40	120.8	80.5	+9	67.5

Table 4

Measured crack sizes at 60% of the ultimate load during the three-edge-bearing tests on all the concrete pipes with and without steel fibres

Type of pipe	Pipe No. 1		Pipe No. 2		Pipe No. 3	
	Width of crack (mm)	Length of crack (mm)	Width of crack (mm)	Length of crack (mm)	Width of crack (mm)	Length of crack (mm)
Elliptical	N/A	N/A	N/A	N/A	N/A	N/A
RCP	0.22	271	0.28	297	0.24	266
SFCP-ZP-25	0.10	117	0.08	153	0.07	169
SFCP-ZP-40	0.03	93	0.06	87	0.03	91
SFCP-80/60-25	0.02	85	0.02	83	0.02	79
SFCP-80/60-40	0.02	53	0.02	48	0.02	50

requirement. These SFCP-80/60-25 class pipes of our study satisfy even the highest class, Class H, as specified in Table 3 of BS-DD-76-Part-2 [13], also, because 78 kN/m is greater than 58 kN/m, the lower limit for Class H pipes of 525 mm internal diameter.

According to the Turkish Standard TS-821-EN-1916 [6] the lower acceptable limit of 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'' plain concrete pipe [16]. The plain-concrete pipe of our study has an average three-edge-bearing strength of 43 kN/m.

3. Effect of steel fibres dosage on three-edge-bearing strength

The experimental findings of three-edge-bearing strengths of steel-fibre concrete pipes per unit effective length of pipe are summarized in Fig. 5. The relationships between the ultimate load per meter of effective length of pipe versus the steel fibres dosage for steel-fibre concrete pipes are given separately for ZP 308 and RN 80/60 types of steel fibres in Fig. 5 as compared to the classically reinforced-concrete pipe.

The strength of steel-fibre concrete pipe having the ZP 308 type of fibre at a dosage of 25 kg/m^3 is smaller than that of the reinforced-concrete pipe. When its dosage is increased to 40 kg/m^3 the strength improves and it exceeds that of the reinforced-concrete pipe slightly. The performance of the steel-fibre concrete pipes having the longer RN 80/60 type of fibre however is much better than the ZP 308 type. This is probably because of too short length and diameter of the ZP 308 fibres. Then, we can say in this study that the longer and more commonly used RN 80/60 type of steel fibres should be preferred in concrete pipes. The experimentally-obtained relationships given in Fig. 5 can be a useful design guide for similar pipes.

Conclusions

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

With the more common RC80/60-BN types of steel fibres, the optimum dosage of steel fibres should be around 25 kg/m^3, and an increase of steel fibres dosage from 25 kg/ m^3 up to 40 kg/m^3, a 60% increase in the mass of steel fibres used, provides only negligibly small improvements in strength and cracking in steel-fibre concrete pipes. The longer RC80/60-BN type of steel fibres seems to be more efficient for steel-fibre concrete pipes than the shorter ZP308 type, and hence, the latter should not be used in steel-fibre concrete pipe production for pipes of diameters beyond 500 mm.

The three-edge-bearing strength of steel-fibre concrete pipes with a steel fibres dosage of 25 kg/m^3 are 6% greater than and 15% better than those of reinforced-concrete pipes having an elliptical reinforcement of 5.1 cm^2 of S420 type of steel for one meter length of pipe, respectively.

Cracking of steel-fibre concrete pipes with a steel fibres dosage of 25 kg/m^3 is much better than that of reinforced-concrete pipes having an elliptical reinforcement of 5.1 cm^2 of S-420 type of steel for one meter length of pipe, also.

Manufacturing of the steel cage reinforcement is more labour-intensive and more-time consuming than simply pouring the steel fibres in to the pan-mixer of the concrete plant, also.

Because of all the four tangible results listed above, pipes produced by C35 class concrete containing steel fibres of the common RC80/60-BN type at a dosage of about 25 kg/m^3 should have more advantageous physical, mechanical, and economical peculiarities over classically reinforced-concrete pipes.

References

[1] Tan KH, Paramasivam P, Tan KC. Cracking characteristics of reinforced steel fiber concrete beams under short- and long-term loadings. Adv Cement Based Mater 1995;2(4):127–37.

[2] Mindees S, Chen L, Morgan DR. Determination of the first-crack strength and flexural toughness of steel-fiber reinforced concrete. Adv Cement Based Mater 1994;1(5):201–8.

[3] Yi CK, Ostertag CP. Strengthening and toughening mechanisms in microfiber reinforced cementitious composites. J Mater Sci 2001;36(6):1513–22.

[4] ACI, ACI-544.4R-88 Design considerations for steel fibre reinforced concrete, American concrete institute. ACI committee 544; 1988 (Reapproved 1999).

[5] TSI, TS-10514 Concrete-steel fibre reinforced-rules for mixing concrete and control. Turkish standards institute, Necatibey Street, 112, Ankara: Turkey; 1992.

[6] TSI, TS-821–EN-1916 Concrete pipes and fittings, unreinforced, steel fibre, and reinforced. Turkish standards institute, Necatibey Street, 112, Ankara: Turkey; 1998.

[7] Altun F, Haktanir T. A comparative experimental investigation of steel fibre added reinforced concrete beams. Mater De Construccio´n 2004;54(276):5–15.

[8] Dupont D, Vandewalle L. Bending capacity of steel fibre reinforced concrete (SFRC) beams. International congress on challenges of concrete construction. In: Proceedings of the international conference on innovations and developments in concrete materials and construction, Dundee; 2002. p. 81-90.

[9] TSI, TS-EN-197-1 Cements – Part 1: compositions and conformity criteria for common cements. Turkish standards institute, Necatibey Street, 112, Ankara, Turkey; 2004.

[10] ASTM, ASTM-C-150-04: Standard specification for portland cement. American society for testing and materials; 2004.

[11] TSI, TS-10513 steel fibres for concrete reinforcement. Turkish standards institute, Necatibey Street, 112, Ankara: Turkey; 1992.

[12] Institut fu¨r Bautechnik, Rohre aus Stahlfaserbeton (Steel-fibreconcrete pipe), Zulassungsbescheid, Anstalt des o¨ffentlichen Rechts: Germany; 1988.

[13] BSI, BS-DD-76-Part-2: Draft for development, precast concrete pipes strengthened by chopped zinc-coated steel fibres. British standards institution; 1983.

[14] ASTM, ASTM-C76M-03: Standard Specification for reinforced concrete culvert, storm drain, and sewer pipe [metric]. American society for testing and materials; 2003.

[15] ASTM, ASTM-C497-03a: standard test methods for concrete pipe, manhole sections, or tile. American society for testing and materials; 2003.

[16] ASTM, ASTM-C14M-04: standard specification for concrete sewer, storm drain, and culvert pipe [metric]. American society for testing and materials; 2004.