Available online at www.sciencedirect.com

SCIENCE DIRECT

Cement and Concrete Research 35 (2005) 2360 – 2363

Cement and Concrete Research

Effect of steel fiber on the deicer-scaling resistance of concrete

Yang Quanbing*, Zhu Beirong

Research Lab of Materials Engineering, Tongji University, 100 Wu Dong Road, Shanghai 200433, China

Received 10 December 2003; accepted 5 April 2005

Abstract

Effects of steel fibers on the deicer-scaling resistance of concrete were investigated in this paper. Results show that the deicer-scaling resistance of concrete is reduced by the addition of steel fibers at the same air content, especially for the air-entrained concrete, even though the flexural strength of concrete is significantly improved by the addition of fibers. The reason is that the average air-void spacing factor of concrete becomes larger due to the addition of steel fibers. The variations in the deicer-scaling resistance among the different concrete qualities can be fully explained by the spacing factor values.

Keywords: Steel fiber; Concrete; Deicer-scaling resistance; Air-void structure

1. Introduction

There are many data available on the mechanical properties of steel fiber reinforced concrete [1–3], and all of them show that steel fibers significantly improve most mechanical properties of concrete. However, there are little data on the deicer-scaling resistance of steel fiber reinforced concrete [4,5]. Pigeon, et al. obtained that the use of steel and particularly carbon microfibers improves the frost and deicer salt scaling resistance of mortars [4]. The reason for improvement is however mainly that the mortars with the fibers have much higher air content than those without the fibers and therefore have much lower spacing factor. Cantin and Pigeon's results indicated that steel fibers have no significant influence on the deicer-scaling resistance of concrete because the best and the worst overall performances were both achieved with fiber-reinforced concretes [5].

With the progress in economy and concrete technology, the applications of steel fiber reinforced concrete in pavements and bridges become more and more common in China [6,7], and deicer salts have been widely used since 1980. In the north of China, serious scaling damage also occurred on the surface of concrete with or without steel fiber due to the presence of deicer. The experiments presented here were carried out to investigate the effect of steel fibers on the deicer-scaling resistance of concrete.

2. Experimental

2.1. Raw materials and proportions

42.5 ordinary Portland cement with a specific area of 340 m^2/kg according to Chinese standard GB175-199 [8], crushed stone with a maximum size of 25 mm, quartz sand with a fineness modulus of 2.52, MR lignosulfonate water-reducing agent with low air-entrained effect, SJ-2 saponin air-entraining agent [9] and steel fiber with a size of length 35 mm × width 1 mm × thickness 0.5 mm were used. 10-cm cubes and 10 cm × 10 cm × 40-cm prisms were manufactured and compacted by vibration for about 15 s. In order to avoid the possible effects of demoulding agents on the deicer-scaling resistance of concrete, no demoulding agent was used on the surfaces of molds. The specimens were demoulded and immersed in water at 20 ± 2 °C after at an age 24 h. The prisms were used for measuring the flexural strength of concrete, and the cubes

* Corresponding author. Tel.: +86 21 65901281; fax: +86 21 6590 1021.
E-mail address: qbyang@mail.tongji.edu.cn (Y. Quanbing).

0008-8846/$ - see front matter © 2005 Elsevier Ltd. All rights reserved.
doi:10.1016/j.cemconres.2005.04.003

Table 1
Mix proportions and properties of fresh concrete

No.	Cement, kg/m^3	Water, kg/m^3	Sand, kg/m^3	Stone, kg/m^3	Fiber, %[a]	MR, kg/m^3	SJ-2, kg/m^3	Slump, mm	Air, %[a]
A0	340	170	626	1216	/	/	/	30	1.0
A1	340	170	626	1210	0.25	/	/	25	0.9
A2	340	170	626	1203	0.5	/	/	20	1.0
A3	340	170	626	1196	1.0	/	/	10	1.2
B0	340	163	602	1222	/	0.40	0.034	50	3.2
B1	340	163	602	1216	0.5	0.30	0.026	45	3.0
C0	340	158	604	1226	/	0.40	0.034	60	4.6
C1	340	158	604	1220	0.5	0.40	0.034	50	4.2
D0	340	146	593	1232	/	0.70	0.06	50	5.5
D1	340	146	593	1226	0.25	0.70	0.06	45	5.7
D2	340	146	593	1219	0.5	0.70	0.06	35	6.3
D3	340	146	593	1212	1.0	0.70	0.06	20	6.5

[a] Volume percent.

were used for the compressive strength and deicer-scaling tests.

Steel fiber reinforced concrete was designed with the additions of 0.25%, 0.5% and 1.0% steel fiber, which replaced an equal volume of the crushed stone. The mix proportions and some properties of fresh concrete are listed in Table 1.

2.2. Deicer-scaling test

The deicer-scaling test used here is similar to the RILEM 117-FDC/CDF test method [10]. However, one freeze–thaw cycle involves freezing at -20 ± 2 °C, for 3 h, and then thawing at 20 ± 5 °C°C for 3 h. The temperature sensor is put at the bottom of specimen. The deicer solution is 4% NaCl. After curing in water for 28 days, a single surface of the specimen is immersed in the 4% NaCl solution to a depth of about 5 mm in a plastic container that is covered by a tight lid during the test, as shown in Fig. 1. The immersed surface was vertical during casting. The deicer solution is changed about every seven cycles. Four specimens are measured for each test.

This test method is recommended as the Chinese standard method on estimating the deicer-scaling resistance of concrete. In China, the applications of air-entrained concrete in pavements and bridges have been caused concern recently, with the types and quality of air-entraining agents varying greatly. A test method is required which can estimate deicer-scaling resistance more rapidly than the RILEM 117-FDC/CDF test. The Chinese

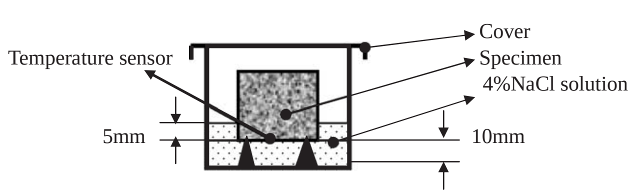

Fig. 1. The method of deicer-scaling test.

Table 2
Properties of hardened concrete

No.	Strength at 28 days, MPa		A, %	α, mm^{-1}	L, μm	Scaling, kg/m^2				
	CS	FS				7C	20C	22C	30C	60C
A0	51.6	6.2	0.92	12.1	847	0.60	4.15	4.44	/	/
A1	48.4	7.0	1.1	11.2	858	0.72	4.20	4.64	/	/
A2	50.5	8.3	1.0	10.8	896	0.64	4.76	5.29	/	/
A3	49.6	9.2	1.3	10.0	900	0.61	4.84	5.82	/	/
B0	52.8	7.4	2.9	24.5	252	0.12	0.56	/	0.89	1.84
B1	50.3	8.5	3.1	21.1	284	0.36	0.92	/	1.54	2.50
C0	52.5	7.7	4.1	23.6	222	0	0.11	/	0.17	0.60
C1	53.0	8.1	4.4	20.4	248	0.18	0.35	/	0.51	1.41
D0	46.8	7.0	5.0	26.2	179	0	0	/	0	0.30
D1	49.5	7.2	4.9	23.7	213	0	0.1	/	0.21	0.58
D2	48.8	8.7	5.2	21.2	226	0	0.19	/	0.30	0.74
D3	50.1	10.9	5.0	20.1	234	0	0.28	/	0.39	0.88

CS, compressive strength; FS, flexural strength; A, air content; α, air specific area; L, average air-void spacing factor; C, freezing–thawing cycles; /, no measuring.

standard method meets this need, and has proved to provide results which are consistent with RILEM 117-FDC/CDF [11].

3. Results and discussion

3.1. Properties of fresh concrete

Table 1 shows that the slump of concrete is reduced, and the larger the addition of steel fibers, the more obvious the effect, but the air content is little changed by the addition of steel fibers.

3.2. Strength

Properties of hardened concrete are seen in Table 2. It can be seen that steel fibers have little effect on the compressive strength of concrete, but significantly improve flexural strength.

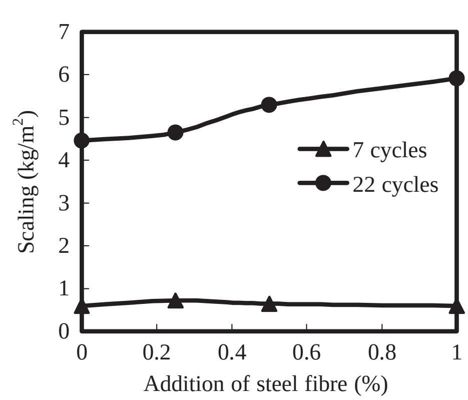

Fig. 2. Effect of fiber on the deicer-scaling resistance of non-air-entrained concrete.

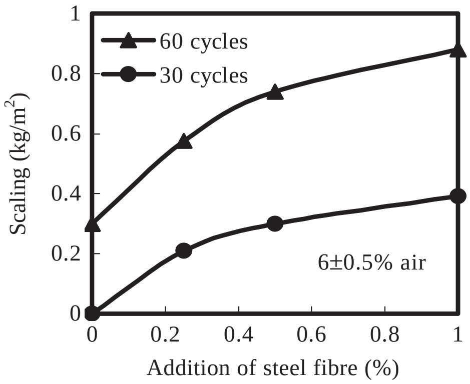

Fig. 3. Effect of fiber on the deicer-scaling resistance of air-entrained concrete.

3.3. Deicer-scaling resistance

Effects of steel fibers on the deicer-scaling resistance of concrete are shown in Table 2; Figs. 2 and 3. It can be clearly seen that the deicer-scaling resistance of concrete is not improved even though the flexural strength of concrete is enhanced by the addition of steel fibers, but is reduced with the increase in the addition of steel fibers at the same air content, and the differences in the deicer-scaling resistance among these concretes become more obvious at more freezing–thawing cycles, especially for air-entrained concrete. For example, for non-air-entrained concrete, the scaling of concrete with 1% steel fiber is 31% higher than that of concrete without steel fiber at 22 cycles; for air-entrained concrete, the scaling of concrete with 1% steel fiber is 193% higher than that of concrete without steel fiber at 60 cycles.

3.4. Air content

From Figs. 2 and 3 it is shown that the problem on the deicer scaling cannot be solved only by the addition of steel fibers. The effect of air content on the steel fiber reinforced concrete is seen in Fig. 4. The deicer-scaling resistance of the steel fiber reinforced concrete is obviously improved with the increase in air content, and the same effect is seen in concrete without steel fibers. The use of air-entraining agents is therefore an important measure to protect the steel fiber reinforced concrete from deicer scaling. However, to achieve the same level of deicer-scaling resistance, the air content of the steel fiber reinforced concrete must be higher than that of concrete without steel fiber. For example, the air content of the concrete with 0.5% steel fiber must be 1% higher than that of concrete without steel fiber in order to achieve scaling of less than 1.0 kg/m^2 at 60 cycles.

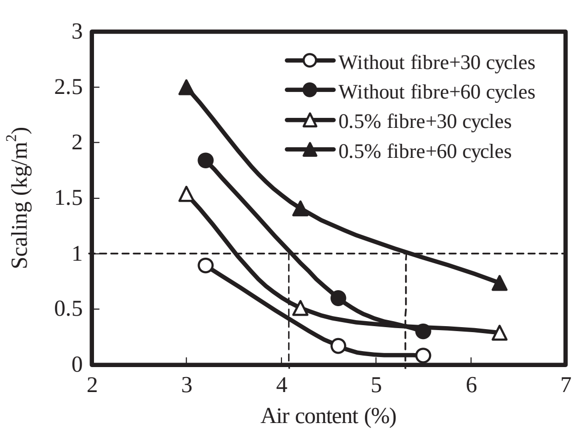

Fig. 4. Effect of air content on the deicer-scaling resistance of concrete with 0.5% steel fiber.

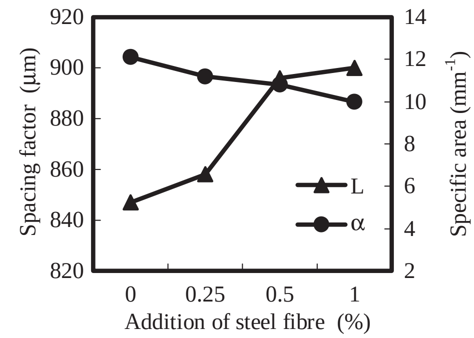

Fig. 5. Effect of steel fiber on the air-void structure of non-air-entrained concrete.

3.5. Analysis of air-void structure

In order to explain above results, parameters of the air-void structure were analyzed according to Chinese standard JTJ225-87, the same as ASTM C 457, results shown in Table 2; Figs. 5 and 6. From these results it is seen that the addition of steel fibers worsens the air-void structure, especially for the air-entrained concrete. The specific surface area of hardened concrete is obviously reduced, but the average spacing factor increases with the increase in the addition of steel fibers. The reason may be that the reduction of slump makes the air-voids in concrete become coarser. For example, for non-air-entrained concrete, the specific surface area of concrete with 1% steel fiber is 17% lower, and the average spacing factor is 6% higher than that

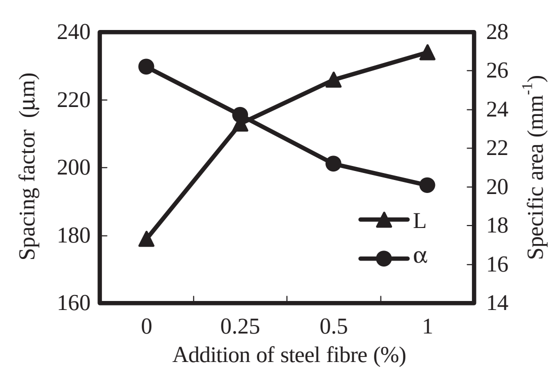

Fig. 6. Effect of steel fiber on the air-void structure of air-entrained concrete.

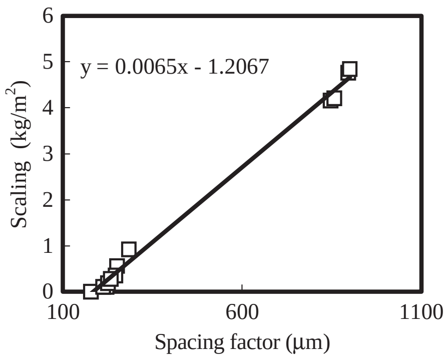

Fig. 7. The relationship between scaling and spacing factor of concrete.

of concrete without steel fiber. For air-entrained concrete, the specific surface area of concrete with 1% steel fiber is 23% lower, and the average spacing factor is 31% higher than that of concrete without steel fiber.

The relationship between scaling and average air-void spacing factor of concrete is shown in Fig. 7. As can be seen, the relationship is very consistent. This suggests that the variations in the deicer-scaling resistance among the different concrete qualities can be best explained by the spacing factor values.

Furthermore, the presence of fiber–matrix interfaces may also promote deicer scaling. From the deicer-frost test it can be observed that the fibers in scaled-off concrete do not bond to the cement mortar, and some fibers have rust spots.

4. Conclusions

Based on the above results, the addition of steel fibers has the following effects on concrete: (1) reducing the slump; (2) increasing the flexural strength; (3) reducing the deicer-scaling resistance.

The air specific area of hardened concrete is reduced, and the average spacing factor increases with the increase in the addition of steel fibers, making the air-voids in concrete become coarser. It is an important cause for the reduction of the deicer-scaling resistance of steel fiber reinforced concrete.

The variations in the deicer-scaling resistance among the different concrete qualities can be explained by the spacing factor values.

Acknowledgement

The authors are grateful to the Science and Technology Fund of Western Transportation Construction, Ministry of Communications of China, for the financial support. The work described is part of the supported project 2001-31878877-(4).

References

[1] J.A. Mandel, W. Sun, Studies of the properties of fiber matrix in steel fiber reinforced mortar, ACI Materials Journal 84 (2) (1987) 101–109.
[2] C. Liu, Y. Ju, Study on mechanical properties of steel fiber reinforced concrete, Concrete and Cement Products 115 (1) (2000) 16–19 (in Chinese).
[3] A.E. Naaman, J.R. Homrich, Tensile stress–strain properties of SIFCON, ACI Materials Journals 86 (3) (1989) 369–377.
[4] M. Pigeon, R. Pleau, M. Azzabi, N. Banthia, Durability of microfiber-reinforced mortars, Cement and Concrete Research 26 (4) (1996) 601–609.
[5] R. Cantin, M. Pigeon, Deicer scaling resistance of steel-fiber-reinforced concrete, Cement and Concrete Research 26 (11) (1996) 1639–1648.
[6] Q. Cheng, Y. Xu, Research, application and development of steel fiber reinforced concrete, Concrete and Cement Products 115 (1) (2000) 5–9 (in Chinese).
[7] C. Lan, B. Luo, Application of steel fiber reinforced concrete in pre-stressing beams of bridge, Concrete and Cement Products 115 (1) (2000) 111–113 (in Chinese).
[8] Chinese Standard GB175-1999, Portland Cement and Ordinary Portland Cement, 1999.
[9] Q. Yang, P. Zhu, X. Wu, S. Huang, Properties of concrete with a new type of saponin air-entraining agent, Cement and Concrete Research 30 (8) (2000) 1313–1317.
[10] RILEM Committee TC117-FDC, Test method for the freeze–thaw resistance of concrete with water (CF) or with sodium chloride solution (CDF), Materials and Structures 28 (5) (1995) 175–182.
[11] Q. Yang, Parameters estimating the deicer-scaling resistance of concrete, Low Temperature Architecture Technology 5 (2004) 4–6 (in Chinese).