Modeling Abrasion Resistance of Concrete Floors

Quartarly Journal of Technology & Education
Vol.1, Special issue, Autumn 2006

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Abstrac

Abrasion of industrial concrete floors is a major problem resulting in their lower service lives. Attempt has been made to relate the abrasion resistance of concrete to its compressive strength. However there are other factors which influence the abrasion resistance of concrete.

In this study, several concrete mixtures containing different types of cements, aggregates, admixtures and additives such as silica fume and styrene butadiene rubber (S.B.R) polymer were made to assess their abrasion resistances. All concrete specimens were tested for wear action in accordance with ASTM and EN standard test methods. Based on data obtained from the tests, an empirical model was proposed to evaluate the abrasion resistance of different concretes.

Results of this investigation show that the incorporation of silica fume, S.B.R polymer and granite aggregates in concrete improve its abrasion resistance. The proposed mathematical model is capable to predict the abrasion resistance of concrete and provide a guide for selection of materials to produce more durable concrete when subjected to wear action.

Keywords

abrasion resistance, concrete, durability, industrial floors, mathematical model, silica fume, styrene butadiene rubber (S.B.R) polymer

INTRODUCTION

The abrasion resistance of a concrete slab in an industrial area can be defined as the ability of the concrete surface to resist being worn away by rubbing, rolling, sliding, cutting and impact forces[1]. Abrasion resistance of concrete is influenced by many factors. Similar to other concrete properties, abrasion of concrete is also depends on the compressive strength[2,3]. Apart from cementitious materials, other materials such as pozzolans and polymers improve the abrasion resistance of concretes[4]. In industrial floors the usage of epoxies with special components and in hydraulic structures using some resins have been suggested[5,6].

However, these methods are not cost-effective and laboratory studies are useful to find acceptable methods in such conditions.

In this research the abrasion resistance of concrete floors, in particular the factors affecting abrasion resistance, such as water-cementitious materials ratios (w/cm), aggregate type, silica fume and S.B.R polymer and finishing method were investigated. A mathematical model was developed to predict the abrasion resistance of concrete.

EXPERIMENTAL PROGRAM

Test methods

Simulation of the abrasion-erosion of structures in laboratory scale is difficult, but the standard tests are very helpful for comparison purposes. The suggested methods of ASTM for testing the abrasion resistance of concrete are:

a) ASTM C 418, standard test method for abrasion resistance of concrete by sandblasting[7].

b) ASTM C 779, standard test method for abrasion resistance of horizontal concrete surface[8].

c) ASTM C 944, standard test method for abrasion resistance of concrete or mortar surfaces by rotating-cutter method[9].

To evaluate the abrasion resistance of concrete floors, the ASTM C779-a standard test method was selected and, as shown in Figs. 1 and 2, the apparatus containing revolving disk system was manufactured and calibrated for the test procedures.

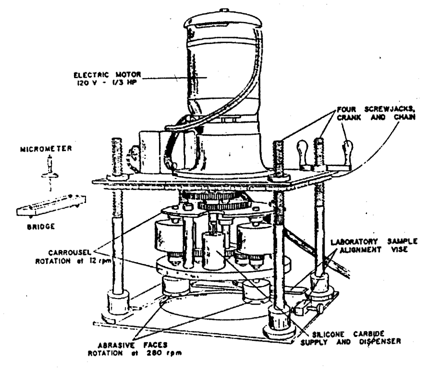

Fig 1 Revolving disk system in accordance with ASTM C 779-a

Fig 2 Manufactured revolving disk apparatus based on ASTM standard

The EN 1338[10] standard test method was used for comparison purposes (see Fig. 3).

Fig 3 Abrasion test apparatus based on EN standard

Materials

Cement-- ASTM Type II portland cement was used in this study. The chemical analysis

of the cement is shown in Table 1.
Silica fume-- Silica fume was obtained from a local factory. Chemical analysis of the silica fume is shown in Table 1.

Table 1 Chemical analysis of cementitious materials

(%)	Type II	Silica fume
SiO_2	20.96	95.1
Al_2O_3	4.2	0.6
CaO	61.88	1.02
MgO	3.4	0.6
Fe_2O_3	4.6	1.1
SO_3	1.79	1.2
C_3S	52.74	-
C_2S	20.31	-
C_3A	3.35	-
Na_2O+0.658 K_2O	1.47	-
Loss on ignition (%)	1.24	-

Aggregates- Ordinary, granite and siliceous aggregates were used throughout this investigation. The specific gravity, water absorption and abrasion values of the aggregates are depicted in Table 2.

Table 2 Aggregate properties

Type of aggregate		Specific Gravity	Absorption (%)	Los Angeles weight losses (%)
Gravel	Granite	2.8	0.87	14.3
	Ordinary aggregate	2.5	1.63	17.6
	Siliceous aggregate	2.65	1.24	17.6
Sand	Natural river-bed	2.5	1.42	-

Superplasticizer- A melamine-based superplasticizer was used in the mixtures to reach to a constant slump.

Mixture proportions

74 concrete mixtures were prepared for this investigation. Concrete constituent variations are summarized in Table 3. As shown in this table, silica fume and SBR polymer were between 0 to 10 percent of the cementitious materials weight. Water-cementitious materials ratios of the mixtures were varied from 0.35 to 0.45.

Table 3 Mixture proportions

Silica fume (%)	S.B.R (%)	Coarse Agg. (kg)	Fine Agg. (kg)	Cement (kg)	Water (kg)	w/cm
0-10	0-10	950 ± 50	800 ± 50	360-400	90-140	0.35, 0.4, 0.45

Test Program

Specimens were prepared and cured in accordance with standard test methods. Some of surfaces of the specimens were troweled by hand and some finished with a machine to investigate the effect of finishing on the abrasion resistance of concrete. The specimens were tested at the ages of 3, 7, 28 and 90 days with two different test methods. Compressive strength of ages.

concrete specimens were determined at the same
The dimensions of the specimens for ASTM abrasion tests were 305×305×95 mm for EN abrasion tests were 100×100×80 mm, and for compressive strength tests were 150×150×150 mm.

Approximately 1400 abrasion tests were carried out for both ASTM and EN standard test methods. Some of the results are summarized in Tables 4-7.

Table 4 Results of abrasion test for granite aggregate at 28 days (ASTM method)

w/cm	Silica fume (%)	S.B.R (%)	f_c (Mpa)	Hand finishing	Machine finishing
				Abrasion depth (mm)	Abrasion depth (mm)
0.45	0	0	26.52	0.40	0.33
0.40	0	0	31.83	0.36	0.33
0.35	0	0	44.59	0.37	0.28
0.45	5	0	25.87	0.35	0.33
0.40	5	0	44.21	0.27	0.24
0.35	5	0	42.95	0.29	0.24
0.45	10	0	38.93	0.28	0.26
0.40	10	0	44.08	0.31	0.22
0.35	10	0	53.36	0.29	0.19
0.45	0	5	25.85	0.42	0.29
0.40	0	5	41.54	0.31	0.23
0.35	0	5	44.24	0.30	0.24
0.45	5	5	36.32	0.36	0.25
0.40	5	5	38.12	0.29	0.22
0.35	5	5	44.35	0.22	0.19
0.45	10	5	36.36	0.28	0.21
0.40	10	5	34.78	0.25	0.24
0.35	10	5	45.14	0.21	0.19
0.45	0	10	28.77	0.37	0.29
0.40	0	10	39.17	0.30	0.23
0.35	0	10	49.58	0.26	0.20
0.45	5	10	27.92	0.29	0.25
0.40	5	10	31.58	0.31	0.23
0.35	5	10	44.86	0.20	0.19
0.45	10	10	30.07	0.23	0.25
0.40	10	10	48.67	0.20	0.16
0.35	10	10	57.21	0.19	0.15

Table 5 Results of abrasion test for granite aggregate at 90 days (ASTM method)

w/cm	Silica fume (%)	S.B.R (%)	f_c (Mpa)	Hand finishing	Machine finishing
				Abrasion depth (mm)	Abrasion depth (mm)
0.45	0	0	36.34	0.47	0.32
0.40	0	0	44.33	0.34	0.25
0.35	0	0	46.75	0.29	0.26
0.45	5	0	30.82	0.38	0.28
0.40	5	0	35.57	0.31	0.29
0.35	5	0	62.01	0.22	0.19
0.45	10	0	32.38	0.36	0.28
0.40	10	0	51.55	0.28	0.21
0.35	10	0	52.89	0.24	0.20
0.45	0	5	29.5	0.36	0.28
0.40	0	5	37.67	0.26	0.23
0.35	0	5	45.36	0.27	0.22
0.45	5	5	40.38	0.27	0.20
0.40	5	5	42.23	0.25	0.20
0.35	5	5	47.52	0.24	0.19
0.45	10	5	40.74	0.27	0.21
0.40	10	5	46.22	0.21	0.17
0.35	10	5	51.50	0.19	0.18
0.45	0	10	30.02	0.35	0.26
0.40	0	10	42.56	0.26	0.21
0.35	0	10	51.15	0.24	0.17
0.45	5	10	34.43	0.29	0.21
0.40	5	10	44.19	0.20	0.18
0.35	5	10	55.76	0.19	0.17
0.45	10	10	39.44	0.25	0.19
0.40	10	10	53.90	0.23	0.15
0.35	10	10	51.61	0.20	0.15

Table 6 Results of abrasion test for ordinary aggregate at 28 days (ASTM method)

w/cm	Silica fume (%)	S.B.R (%)	f_c (Mpa)	Hand finishing	Machine finishing
				Abrasion depth (mm)	Abrasion depth (mm)
0.45	0	0	22.89	0.76	0.52
0.40	0	0	24.33	0.63	0.53
0.35	0	0	37.75	0.47	0.40
0.45	5	0	19.03	0.57	0.51
0.40	5	0	34.49	0.50	0.35
0.35	5	0	42.45	0.45	0.29
0.45	10	0	23.16	0.51	0.46
0.40	10	0	32.01	0.45	0.37
0.35	10	0	33.87	0.39	0.39
0.45	0	5	21.00	0.59	0.54
0.40	0	5	30.64	0.51	0.42
0.35	0	5	26.60	0.48	0.43
0.45	5	5	20.26	0.65	0.45
0.40	5	5	31.77	0.49	0.34
0.35	5	5	34.46	0.33	0.35
0.45	10	5	28.52	0.50	0.36
0.40	10	5	33.22	0.34	0.30
0.35	10	5	32.05	0.31	0.32
0.45	0	10	21.09	0.62	0.45
0.40	0	10	22.76	0.58	0.46
0.35	0	10	36.04	0.39	0.30
0.45	5	10	21.89	0.51	0.40
0.40	5	10	31.29	0.44	0.32
0.35	5	10	30.80	0.35	0.30
0.45	10	10	25.13	0.37	0.34
0.40	10	10	37.18	0.42	0.25
0.35	10	10	38.08	0.29	0.25

Table 7 Results of abrasion test for ordinary aggregate at 90 days (ASTM method)

w/cm	Silica fume (%)	S.B.R (%)	f_c (Mpa)	Hand finishing	Machine finishing
				Abrasion depth (mm)	Abrasion depth (mm)
0.45	0	0	22.24	0.66	0.60
0.40	0	0	23.86	0.73	0.49
0.35	0	0	30.86	0.49	0.43
0.45	5	0	22.43	0.61	0.45
0.40	5	0	32.45	0.53	0.35
0.35	5	0	44.73	0.46	0.32
0.45	10	0	25.34	0.55	0.47
0.40	10	0	31.19	0.38	0.37
0.35	10	0	48.98	0.37	0.30
0.45	0	5	18.52	0.71	0.54
0.40	0	5	31.39	0.53	0.36
0.35	0	5	40.99	0.45	0.31
0.45	5	5	22.66	0.51	0.41
0.40	5	5	29.35	0.42	0.33
0.35	5	5	32.19	0.38	0.34
0.45	10	5	26.97	0.45	0.35
0.40	10	5	37.06	0.44	0.29
0.35	10	5	45.99	0.32	0.23
0.45	0	10	21.39	0.55	0.43
0.40	0	10	26.50	0.55	0.42
0.35	0	10	40.10	0.39	0.29
0.45	5	10	22.66	0.50	0.39
0.40	5	10	35.04	0.40	0.31
0.35	5	10	31.39	0.34	0.29
0.45	10	10	25.40	0.40	0.33
0.40	10	10	31.73	0.33	0.28
0.35	10	10	36.23	0.28	0.30

TEST RESULTS AND DISCUSSION

The relation between the compressive strength and abrasion resistance of concrete mixtures are shown in Figs. 4 to 6. it is clearly seen that the abrasion depth of concrete mixtures decreases with increasing the compressive strength (see Fig. 4).

Figs. 5 and 6 show the effect of silica fume and S.B.R on the abrasion resistance of concrete mixtures. Concrete mixtures containing S.B.R show a better performance than the silica fume concrete mixtures.

MATHEMATICAL MODEL

According to the durability design and in order to predict the abrasion resistance of concrete floors, a mathematical model was developed in this study. This model was adopted based on experimental works. To create the model, firstly the important parameters were separately correlated to the abrasion depth of concrete. Then relationships between the abrasion depth and each factor were assessed. Finally considering simultaneous effects, a general formula was obtained.
The parameters considered in the model were: compressive strength of concrete, aggregate type, percentage of silica fume and S.B.R polymer, and type of finishing. The suggested model is:

$$y = A.B.(5.82)\ f_c^{(-0.684)}.(12sf^2-2.6sf+1).(-46.67R^3+20.86R^2-3.6R+1) \quad (1)$$

In this expression:
y = abrasion depth, mm
A= equal to 1 for ordinary, 0.74 for granite and .86 for siliceous aggregates
B= equal to 1 for hand finishing and 0.79 for machine finishing
f_c = compressive strength of concrete, Mpa
sf = silica fume / cement by weight
R= SBR / cement by weight

The above parameters were calculated by a linear regression from the results of experimental tests.
In this research, three levels of abrasion resistance were defined. High abrasion resistance indicates the abrasion depth between 0 to 0.20 mm, medium abrasion resistance is for 0.21 to 0.45 mm and finally abrasion depth between 0.46 to 0.70 mm is designated as low abrasion resistance.

In order to show the validity of the model, some data obtained in experimental works and the output of the model are shown in Figs. 7-11.

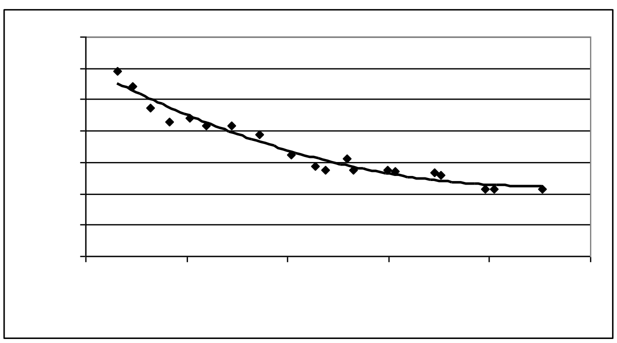

Fig 4- Abrasion depth VS. compressive strength of concrete

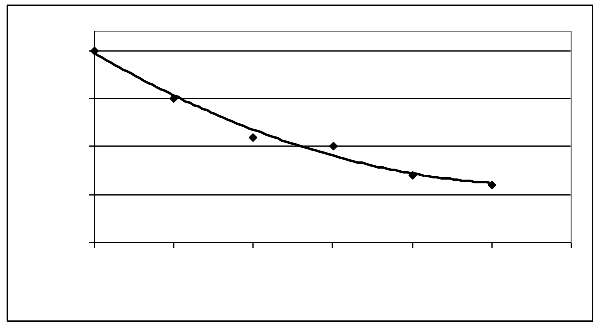

Fig 5- Improvement of abrasion resistance VS. silica fume content

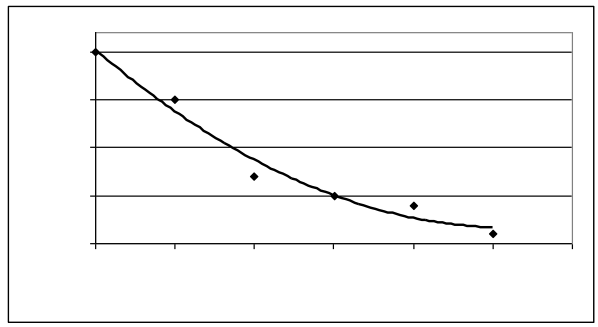

Fig 6- Improvement of abrasion resistance VS. S.B.R polymer content

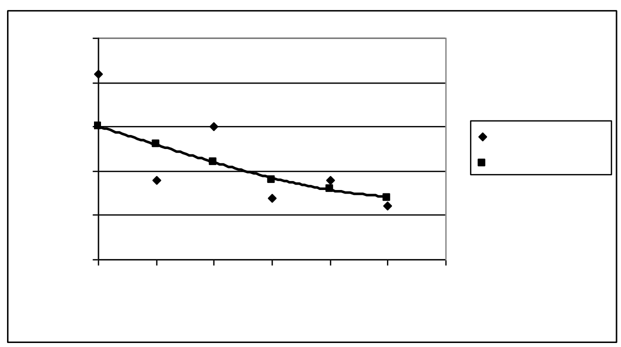

Fig 7- Relationship between abrasion depth and silica fume content

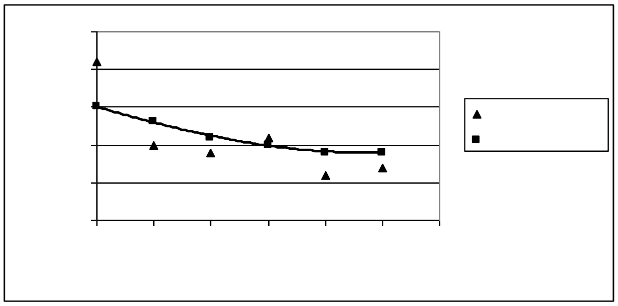

Fig 8- Relationship between abrasion depth and S.B.R polymer content

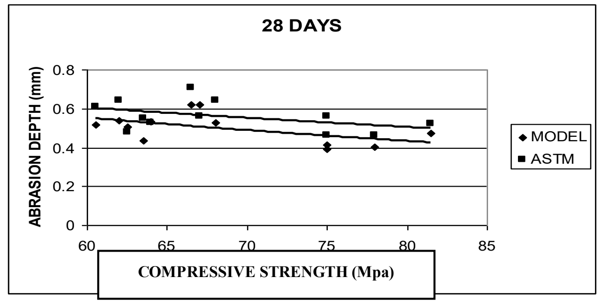

Fig 11- Comparison between suggested model and independent ASTM tests

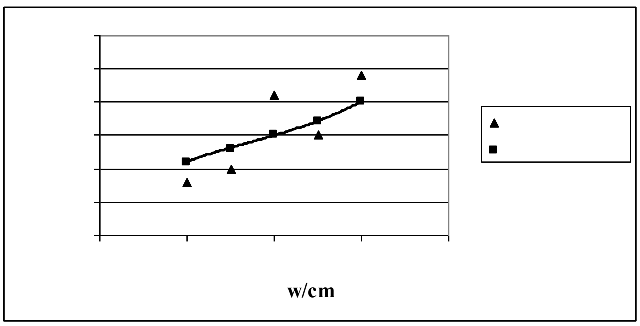

Fig 9- Relationship between abrasion depth and w/cm

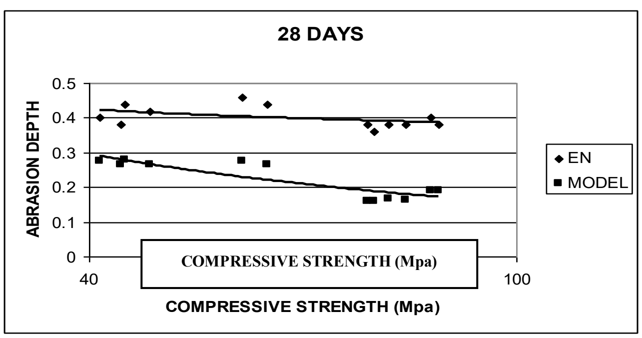

Fig 10- Comparison between suggested model and EN (scaled) tests

CONCLUSION

From the results presented in this paper, the following conclusions are drawn:

a) Granite aggregates improved the abrasion resistance of concrete up to about 35%.
b) Incorporating 10% silica fume, as supplementary cementing materials, decreased the abrasion depth of concrete up to 15%.
c) The use of 10% S.B.R polymer in concrete mixtures resulted in approximately 20% improvement in abrasion resistance of concrete.
d) Decreasing the w/cm ratio and the use of mechanical instruments in the finishing of the concrete floors decreased the abrasion depth of concretes.
e) There was a direct relationship between the compressive strength and the abrasion resistance of concrete specimens.
f) The proposed model with some limitations is capable to predict the abrasion resistance of normal concretes and concretes containing silica fume and SBR polymer.

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