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IMPROVING THE ABRASION RESISTANCE OF MORTAR BY ADDING LATEX AND CARBON FIBERS

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ABSTRACT

The abrasion resistance of mortar was found to be significantly improved by the addition of latex (20% by weight of cement), and further improved by the further addition of short carbon fibers (0.27 vol.%). Both effects relate to the increase in tensile strength. The abrasion resistance was also improved by the addition of silica fume (15% by weight of cement), due to the increase in tensile modulus. The abrasion resistance was better for mortar with silica fume than mortar with latex, but was worse for mortar with silica fume than mortar with latex and carbon fibers. © *1997 Elsevier Science Ltd*

Introduction

The abrasion resistance of concrete is relevant to essentially any application of concrete, as rubbing, scraping, skidding or sliding of objects on the concrete surface commonly occur. Although much attention has been given to the bulk mechanical properties of concrete, whether in compression, tension, flexure or torsion, relatively little attention has been given to the surface mechanical properties such as the abrasion resistance. The constitution of the concrete affects both the bulk and surface mechanical properties. Numerous admixtures (e.g., silica fume, latex and fibers) had been shown to improve the bulk mechanical properties of concrete, but the effects of many of these admixtures on the abrasion resistance of concrete had not been investigated. Silica fume is an admixture that improves the abrasion resistance of concrete (1). Polymer admixtures also help (2). Steel fibers and polypropylene fibers do not affect the abrasion resistance of concrete (3). Cement replacement by fly ash or slag is detrimental to the abrasion resistance (4-6). The coarse aggregate (1) and testing conditions (i.e., air-dry versus wet) (7) significantly affect the abrasion resistance. In this paper, we report the effects of latex and short carbon fibers on the abrasion resistance of concrete. Both latex and carbon fibers were found to improve the abrasion resistance, such that latex is less effective than silica fume but latex together with carbon fibers is more effective than silica fume.

Latex is known to improve both the flexural strength of the concrete and the bond strength between reinforcement (fibers or rebars) and the concrete (8-10). In addition, latex reduces

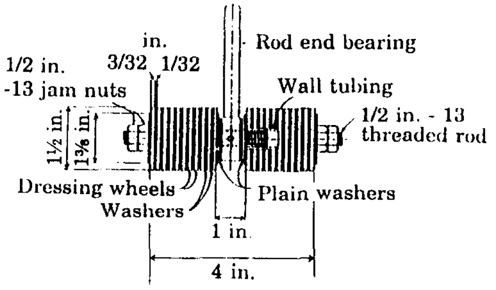

FIG. 1.
Configuration of rotating cutter used for abrasion.

permeability (8) and improves the vibration damping ability (1) and flexural toughness (12,13). Latex in the form of styrene butadiene is particularly common for use in cement (8-17). Short carbon fibers are known to decrease the drying shrinkage and increase the tensile and flexural strengths, tensile ductility and flexural toughness of concrete (17-26), in addition to rendering the concrete to be able to sense its own strain (27,28). The addition of latex to carbon fiber reinforced concrete is attractive, as it increases the tensile, compressive and flexural strengths and flexural toughness (8).

Experimental Methods

The cement used was Portland cement (Type I) from Lafarge Corp. (Southfield, MI). The fine aggregate used was natural sand (all passing #4 US sieve, 99.9% SiO_2). The particle size analysis of the sand is shown in Fig. 1 of Ref. 7. No coarse aggregate was used. The sand/cement ratio was 1.5. The water/cement ratio was 0.45. A water reducing agent (TAMOL SN, Rohm and Haas Co., Philadelphia, PA; sodium salt of a condensed naphthalenesulphonic acid) was used in the amount of 2% of cement weight. All ingredients were mixed in a Hobart mixer with a flat beater. After pouring into square molds of size 6.25 × 6.25 × 1.13 in. (15.9 × 15.9 × 2.86 cm), an external vibrator was used to facilitate compaction and decrease the amount of air bubbles. The samples were demolded after 24 h and then cured in air at room temperature and a relative humidity of 33% for 28 days.

Four types of mortar were studied, namely (i) plain mortar, (ii) mortar with latex, (iii) mortar with latex and carbon fibers, and (iv) mortar with silica fume. The carbon fibers used

TABLE 1

Properties of Carbon Fibers

Filament diameter	10 μm
Tensile strength	690 MPa
Tensile modulus	48 GPa
Elongation at break	1.4%
Electrical resistivity	3.0×10^{-3} Ω.cm
Specific gravity	1.6 g cm^{-3}
Carbon content	98 wt.%

TABLE 2

Densities (g/cm^3, ± 4%) of Mortars

Plain mortar	2.11
Mortar with latex	2.09
Mortar with latex and fibers	2.01
Mortar with silica fume	2.03

were short (nominally 5 mm in length), unsized and made from isotropic pitch. Their properties are shown in Table 1. They were provided under the trade name Carboflex by Ashland Petroleum Co., Ashland, Kentucky. Carbon fibers in the amount of 0.27 vol.% (corresponding to 0.5% by weight of cement) were used. The latex (Dow Chemical, 460 NA) was a styrene butadiene copolymer; it was used in the amount of 20% by weight of cement. An antifoam agent (Dow Corning 2410) in the amount of 0.5% by weight of latex was used whenever latex was used. The silica fume (Elkem Materials, EMS 965) was used in the amount of 15% by weight of cement.

The abrasion resistance was measured using ASTM C944-90a (Rotating-Cutter Method). The rotating cutter involved twenty-four No. 1 Desmond-Huntington grinding dressing wheels (diameter = 1.5 in, thickness = 3/32 in.) and washers (diameter = 1 3/8 in, thickness = 1/32 in.) between the dressing wheels (Fig. 1). The total cutting area was 71.12 cm^2. The load was 10 kgf (98 N) during abrasion. The speed of the rotating cutter was 200 rpm. Each specimen was abraded once on each of its two opposite flat sides, such that each time lasted 2 min. The weight after each time was measured using a balance to an accuracy of 0.1 g. Three specimens of each type of mortar were tested. The average weight loss (average of six values obtained for each type of mortar) was used to compute the depth of wear, using the separately measured density of each mortar (Table 2).

Results

Table 3 gives the depth of wear for each type of mortar. Latex addition improved the abrasion resistance; the further addition of carbon fibers further improved the abrasion resistance. Latex addition was not as effective as silica fume addition in improving the abrasion resistance, but the addition of latex together with carbon fibers was even more effective than the addition of silica fume in improving the abrasion resistance.

Discussion

The effectiveness of latex in improving the abrasion resistance is attributed to the increase in tensile strength of cement paste from 0.88 to 3.03 MPa and increase in flexural toughness of

TABLE 3

Depth of Wear (mm, ± 9%)

Plain mortar	1.07
Mortar with latex	0.161
Mortar with latex and fibers	0.096
Mortar with silica fume	0.145

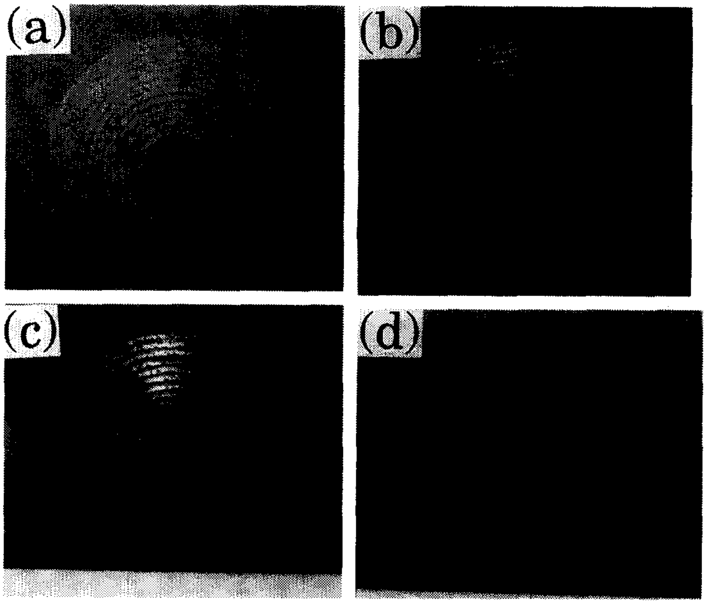

FIG. 2.
Optical photographs of abrasion path of (a) plain mortar, (b) mortar with latex, (c) mortar with latex and fibers, and (d) mortar with silica fume.

mortar from 0.223 to 0.500 MPa.mm (17). The further addition of carbon fibers further increased the tensile strength of cement paste to 3.15 MPa and further increased the flexural toughness of mortar to 0.856 MPa.mm (12). Neither latex nor carbon fibers increased the tensile modulus (12). Silica fume did not increase the tensile strength, but increased the tensile modulus of cement paste from 11 to 40 GPa (13). Thus the origin of the abrasion resistance improvement is different between latex (with or without carbon fibers) and silica fume. The former relates to resistance to fracture, whereas the latter relates to resistance to deform. This explanation is supported by visual observation of the abraded path. The path became black after abrasion for the mortar with latex (with or without carbon fibers), but had no change in color after abrasion for the plain mortar or the mortar with silica fume (Fig. 2). The blackening is believed to be due to the smearing of the latex on the mortar surface during abrasion and the resulting latex coating becoming dirty during abrasion.

Conclusion

The abrasion resistance of mortar was found to be significantly improved by the addition of latex, and further improved by the further addition of short carbon fibers. Both effects relate to the increase in tensile strength and the resulting resistance to fracture. The abrasion resistance was also improved by the addition of silica fume, due to the increase in tensile modulus and the resulting resistance to deform. The abrasion resistance was better for mortar with silica fume than mortar with latex, but was worse for mortar with silica fume than mortar with latex and carbon fibers.

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