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Abrasion and skid resistance of recyclable fly ash concrete pavement made with limestone aggregate

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HIGHLIGHTS

- Fly ash concrete was made with limestone aggregate for cement recyclability.
- Raveling tests were conducted to examine the abrasion resistance.
- British Pendulum Number tests were conducted after the raveling tests.
- The abrasion wear increased gradually with an increase in fly ash volume.

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ABSTRACT

The abrasion and subsequent skid resistance of recyclable concrete pavement using raveling tests with tire chains has been examined, since the abrasion of limestone aggregate-containing concrete pavements is of concern. The recyclable concrete was made by replacing 40% of the cement mass with fly ash concrete. Limestone rock fine and coarse aggregates were mixed in the concrete with a water/cementitious material ratio of 0.33 for early adequate strength. The test results show: (1) the abrasion wear of the recyclable concrete increases gradually with an increase of fly ash; (2) the skid resistance of the recyclable concrete is almost equal skid resistance to the concrete with siliceous aggregate.

1. Introduction

Fly ash is a daily byproduct of coal-burning power plants and is stockpiled. Powder material can improve cement concrete properties when it is used as an alternative cementitious material. To mitigate environmental impacts and improve structural performance, civil engineers should promote the structural application of fly ash in cement concrete. However, most fly ash concrete is less alkaline than conventional concrete, so resistance to carbonation is a concern for its practical use. A typical application of fly ash concrete includes road material because reinforcements are seldom used in rigid pavements.

The focus of this study was on fly ash concrete pavement with a cement replacement ratio of 40%. All aggregates in the concrete were fine, crushed limestones, so all components in the concrete could be used as raw materials in cement production. Yoshitake et al. [1,2] prepared a high-volume fly ash (HVFA) concrete with limestone aggregate, and reported that the hardened concrete had a recyclable chemical composition. The HVFA concrete with limestone aggregate also has a low coefficient of thermal expansion and a low hydration heat. The thermal properties are preferable for use in common pavement concrete that contains a relatively high volume of Portland cement. Limestone is not very resistant to abrasion and its use in concrete for pavements raises concerns. The abrasion resistance of recyclable concrete should be determined to confirm whether it is suitable for use as a pavement material.

Abrasion of fly ash concrete has been examined in several investigations for its application in road pavement. Naik et al. [3] conducted an accelerated abrasion test using HVFA concretes with cement replacement ratios of 50% and 70% by class F fly ash. The HVFA concrete had a lower resistance than the control concrete without fly ash. Naik et al. [4] reported on the physical properties of HVFA concrete in pavement construction and found that class C fly ash concrete was more resistant than class F fly ash concrete.

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Table 1
Fly ash properties and chemical composition.

Density	2.18 g/cm^3
Blaine fineness	3440 cm^2/g
pH	4.6
Loss of ignition	2.7%
Chemical compositions	
SiO_2	58.2%
Al_2O_3	23.3%
Fe_2O_3	3.19%
K_2O	1.38%
CaO	0.98%
MgO	0.55%
SO_3	0.24%
Na_2O	0.19%

Table 4
Chemical composition (%) of hardened fly ash concrete (FA40-134).

Loss of ignition	38.98%
SiO_2	4.54%
Al_2O_3	1.64%
Fe_2O_3	0.59%
CaO	52.89%
MgO	0.41%
SO_3	0.21%
Na_2O	0.05%
K_2O	0.06%
R_2O	0.089%
TiO_2	0.14%
MnO	0.02%
P_2O_5	0.07%
Cl	0.004%

Table 2
Physical and chemical compositions of cement and limestone powder.

	Cement (*C*)	Limestone powder (***LP***)
Density	3.15 g/cm^3	2.70 g/cm^3
Blaine fineness	3185 cm^2/g	5000 cm^2/g
Setting time start-end	2 h. 19 m.–3 h. 22 m.	N/A
Comp. strength at 3 days	28.6 MPa	N/A
At 7 days	46.1 MPa	N/A
At 28 days	62.5 MPa	N/A
Chemical compositions		
CaO	64.3%	55.62%
SiO_2	20.4%	0.09%
Al_2O_3	5.7%	0.010%
Fe_2O_3	2.9%	0.013%
MgO	1.08%	0.35%
SO_3	1.89%	0.00%
Cl^-	0.017%	0.00%
Loss of ignition	2.25%	43.8%

Fig. 1. Raveling test machine.

Naik et al. [5] evaluated experimentally the effect of the source and amount of fly ash on the abrasion resistance of concrete. The class F fly ash concretes with a cement replacement ratio of 40% were found to have an equal abrasion resistance to that without fly ash, whereas the HVFA concrete with 50% or more fly ash had a slightly lower resistance. Atis [6] also examined the abrasion resistance of HVFA concrete pavement by using a Dorry machine. Linear relationships were found to exist between the abrasion and compressive strength, and the HVFA concrete had a better resistance than concrete without fly ash. Atis and Celik [7] reported that a stronger relationship existed between abrasion and flexural strength than between abrasion and compressive strength. Atis [8] conducted a laboratory test using workable and zero-slump HVFA concretes and reported on empirical relationships between abrasion, compressive strength and porosity. Kumar et al. [9] measured the abrasion of HVFA concrete pavement by a sand-blasting method. The test exhibited adequate resistance for very low water to cementitious material ratio (***w/cm***) concrete (0.3) with a cement replacement ratio of 60% whereas all HVFA concretes had a lower resistance than the control concrete. Garcia et al. [10] conducted

Table 3
Mixture proportions of concrete.

No.	0	1	2	3	4
Mix. ID	C.M. [a]	FA0-0	FA20-67	FA40-134	FA40-154
FA/cm [b]	0%	0%	20%	40%	40%
w/cm [c]	0.42	0.33	0.33	0.33	0.33
Water	134 kg/m^3	110 kg/m^3	110 kg/m^3	110 kg/m^3	127 kg/m^3
Cement	320 kg/m^3	334 kg/m^3	267 kg/m^3	200 kg/m^3	230 kg/m^3
Fly ash (***FA***)	0 kg/m^3	0 kg/m^3	67 kg/m^3	134 kg/m^3	154 kg/m^3
Limestone powder	0 kg/m^3	50 kg/m^3	50 kg/m^3	50 kg/m^3	50 kg/m^3
Fine aggregate [d]	701 kg/m^3	871 kg/m^3	850 kg/m^3	820 kg/m^3	727 kg/m^3
Coarse aggregate [e]	1223 kg/m^3	1033 kg/m^3	1029 kg/m^3	1033 kg/m^3	1034 kg/m^3
HRWRA [f]	3.20 kg/m^3	4.34 kg/m^3	4.68 kg/m^3	4.01 kg/m^3	4.22 kg/m^3
AEA [g]	0.0 kg/m^3	1.30 kg/m^3	1.30 kg/m^3	1.30 kg/m^3	1.38 kg/m^3
Slump	0.5 cm	3.0 cm	1.0 cm	2.5 cm	4.5 cm
Air	2.8%	4.0%	4.1%	3.4%	4.3%

[a] Conventional concrete pavement mixture.
[b] Cement replacement ratio of fly ash (by mass).
[c] Water/cementitious material ratio.
[d] Siliceous sand for No. 0; limestone sand for No. 1–4.
[e] Crushed siliceous rocks for No. 0; crushed limestone for No. 1–4.
[f] High range water-reducing agent (polycarboxylic acid water-reducing agent).
[g] Air-entraining agent.