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Solar Reflectance Values of Concrete

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Solar Reflectance Values for Concrete

Intrinsic material properties can minimize the heat island effect

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Surface and air temperatures in urban and suburban areas tend to be higher than those in adjacent rural areas. This phenomenon, commonly known as the heat island effect, is the result of many factors, but the solar energy absorbed by the surfaces of pavement and buildings plays a major role. Because the heat island effect leads to increased demand for air conditioning and amplified levels of air pollution in cities, current and pending environmental rating systems for buildings[1-3] encourage the use of construction materials that efficiently reflect solar radiation and emit heat via radiant energy. We recently conducted a study[4] to see how these properties vary among concrete mixtures containing various cementitious materials and aggregate types.

BASIC TERMS

Solar reflectance

The solar reflectance of an opaque material is a surface property reported on a scale of 0 to 1, with 1 indicating that all of the solar energy striking a surface is reflected back into the atmosphere and 0 indicating that none is reflected. Generally, light-colored materials have higher solar reflectance than dark-colored materials. Color isn't always a reliable indicator of reflectance, however, as visible light represents only 47% of the energy in the solar spectrum. Solar reflectance is also commonly referred to as albedo.

Emittance

Emittance, a measure of how well a surface lets go of heat via radiant energy, is also a surface property reported on a scale of 0 to 1, with 1 indicating 100% emittance. Highly polished aluminum, for example, has an emittance of less than 0.1. A black, nonmetallic surface, however, has an emittance of more than 0.9. Most nonmetallic opaque materials at temperatures encountered in the built environment have emittance values between 0.85 and 0.95.[5]

Solar reflectance index

The solar reflectance index (SRI) is a composite value calculated using the equations in ASTM E1980, "Standard Practice for Calculating Solar Reflectance Index of Horizontal and Low-Sloped Opaque Surfaces." For a given set of environmental conditions, SRI is based on a surface's solar reflectance and emittance.

TARGET VALUES

Existing rating systems[1,2] and a proposed standard[3] provide incentives for building designers to use reflective hardscaping or roofing materials. For example, the Leadership in Energy and Environmental Design Green Building Rating System for New Construction (LEED-NC™) provides Sustainable Sites (SS) Credit 7, "Heat Island Effect." This system allows one point (Credit 7.1) for using paving material with an SRI of at least 29 for a minimum of 50% of the site hardscape (including roads, sidewalks, courtyards, and parking lots). Another point (Credit 7.2) is available for using low-sloped roofing with an SRI of at least 78 or steep-sloped roofing with an SRI of at least 29 for a minimum of 75% of the roof surface. As of August 2006, 62% of LEED projects qualified for Credit 7.1 (the 23rd most commonly achieved point) and 53% qualified for Credit 7.2 (the 31st most commonly achieved point).[6]

The LEED-NC Reference Guide[7] provides a default emittance of 0.9 for concrete and solar reflectance values of 0.35 for "new typical gray concrete" and 0.7 for "new typical white concrete." It also reports default SRI values for new gray and new white concrete of 35 and 86, respectively. The default SRI values for weathered gray and weathered white concrete are 19 and 45, respectively. For comparison, the LEED-NC Reference Guide[7] reports SRI values of 0 and 6 for typical new and weathered asphalt surfaces, respectively.

To meet the LEED-NC SS 7.1 paving material requirement or the LEED-NC SS 7.2 steep-sloped roofing material requirement for an SRI of at least 29, a concrete surface must have a solar reflectance of at least 0.28 using ASTM E1980 and an emittance of 0.90. To meet the LEED-NC SS 7.2 low-sloped roofing material requirement for an SRI of at least 78, a concrete surface must have a solar reflectance of at least 0.64. Currently, to qualify for these points, samples of the paving and roofing materials must be tested to determine the solar reflectance, except default values of some materials are listed in the LEED-NC Reference Guide.

TEST PROGRAMS

Small specimens

Previous research by others[8] was conducted to determine the factors affecting solar reflectance of concrete. The parameters considered in the test program included the colors of the aggregate and cement as well as wetting, soiling, abrasion, and age of the concrete surfaces. In all cases, test specimens were produced using mixtures with 1 part cement, 0.6 parts water, 2.3 parts sand, and 2.8 parts coarse aggregate. Batches were mixed by hand and placed in 4 in. (100 mm) tall, 4 in. (100 mm) diameter plastic molds. After the concrete was rodded, vibrated, and troweled, the molds were sealed. After 1 day, the molds were stripped and the specimens were cured in a saturated environment for 5 days. At the conclusion of curing, a 1 in. (25 mm) thick disk was sliced from the top of each concrete cylinder using a water-cooled, diamond-tipped blade. The disks were then quartered.

When the test batches were prepared, no allowance was made for the absorption of the aggregates. Some of the specimens therefore had insufficient mixing water, the finished surfaces were irregular, and it was difficult to obtain reliable reflectance results. For specimens produced using concrete mixtures with sufficient mixing water, however, the investigators reported:

- Reflectance values for 25-week-old concrete produced with white and gray cement were 0.68 to 0.77 and 0.41 to 0.52, respectively;
- Reflectance values for aged, weathered, or abraded concrete surfaces were affected by the reflectance of the fine aggregate constituents;

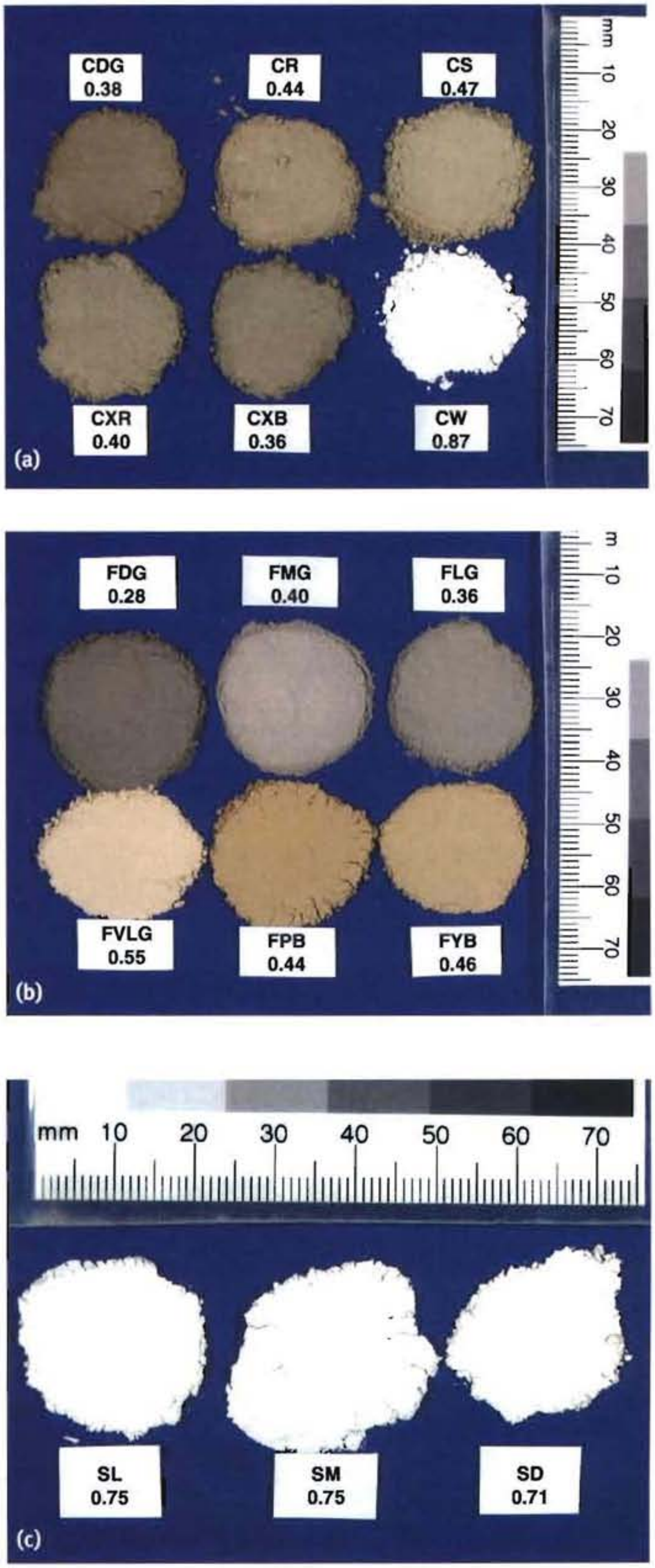

Fig. 1: Cementitious materials used in the current study: (a) portland cements; (b) fly ashes; and (c) slag cements. Numbers on each sample indicate the solar reflectance of the material

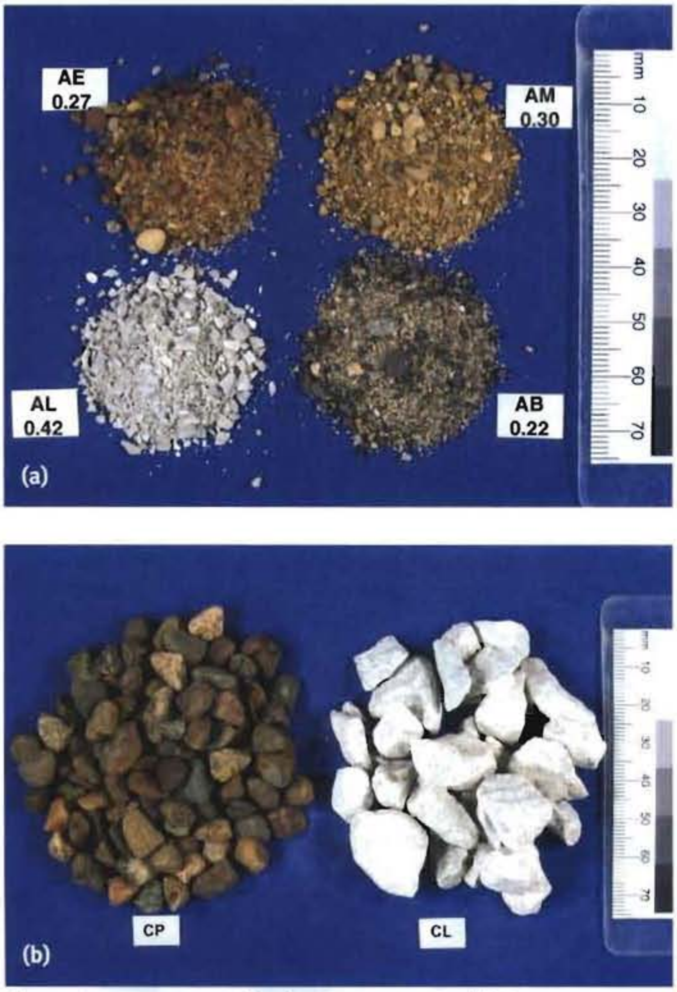

Fig. 2: Aggregates used in the current study: (a) fine aggregates; and (b) coarse aggregates. Numbers on each fine aggregate sample indicate the solar reflectance of the material

Fig. 3: Solar spectrum reflectometer used to measure solar reflectance of the constituent materials and concrete surfaces in this study. The measurement head is the cylindrical piece in the upper right corner

- Concrete reflectance increased with hydration and stabilized at 6 weeks of age, with an average increase of about 0.08; and
- Simulated weathering, soiling, and abrasion reduced the average reflectance of concrete by 0.06, 0.05, and 0.19, respectively.

Flatwork specimens

In the current study, commonly available concrete constituent materials were proportioned, mixed, placed, and finished to replicate typical exterior flatwork. We selected materials, with colors representative of those used throughout the U.S., from hundreds of samples sent to our laboratories. Figure 1 shows samples of the portland cement, fly ash, and slag cement types. Figure 2 shows samples of the fine and coarse aggregates. Except for white portland cement, the portland cements were about the same shade of gray (Fig. 1). Individual particles of fine aggregate (typically erosion sediment largely consisting of granite, quartz, and feldspar) varied in color, and the lightest color fine aggregate was limestone (Fig. 2).

Measuring solar reflectance

Solar reflectance values were measured with a solar spectrum reflectometer (SSR) shown in Fig. 3. For concrete samples, the procedure in ASTM C1549 was followed, but the procedure was modified for measurements of powders (portland cement, fly ash, and slag cement) and fine aggregates. About 0.25 in.^{3} (4 mL) of powder was placed on a 2 x 3 in. (50 x 75 mm) microscope slide, lumps in the powder were broken up, a second slide was placed over the powder, and pressure was applied to flatten the powder into a 2 in. (50 mm) diameter disc. The resulting sample, sandwiched between the two microscope slides, was opaque. The effect of the glass slide on the measured value was eliminated by calibrating the device with a glass slide over a white standard reference material.

For measurements on fine aggregates, about 3 in.^{3} (50 mL) of the aggregate was placed in a 1 in. (25 mm) deep, 2-1/4 in. (60 mm) diameter petri dish. To keep sand or dust particles out of the reflectance measurement head, a polyethylene film was stretched over the measurement port prior to placing the dish in the instrument. The effect of the film on the measured value was eliminated by calibrating the device with the polyethylene film over the measurement port.

For each powder and fine aggregate type, three samples were tested. No measurements were taken on coarse aggregate samples, as the samples were too small to completely cover the measurement port of the SSR, but too large to be measured using a collection of particles in a petri dish. We therefore assumed that solar reflectance values would be identical for coarse and fine aggregates from the same source. Figures 1 and 2 show the measured solar reflectance of the dry concrete constituents.

Mixture proportioning

Constituent materials and combinations were selected to provide mixture proportions suitable for use in exterior flatwork. Target values for the mixtures were 4 in. (100 mm) slump, 4% air content, 0.47 water-cementitious material ratio (*w/cm*), and 0.40 cementitious material-fine aggregate ratio (*cm/fa*). The mixtures were chosen to concentrate on combinations of constituent materials that would produce concrete with low solar reflectance. Table 1 presents the 45 selected mixture proportions.

Specimens

Three specimens measuring 12 x 12 x 1 in. (300 x 300 x 25 mm) were made from each mixture. The constituent materials were mixed in the 0.5 ft^3 (0.014 m^3) pan mixer shown in Fig. 4. The specimens were given a light broom finish, moist cured for 7 days, and placed in a temperature- and humidity-controlled room at a nominal 73 °F (23 °C) and 50% relative humidity to dry for 60 days. Previous research has shown that solar reflectance of concrete remains nearly constant after 6 weeks from casting.[8]

RESULTS

The solar reflectance of the surface of each of the three specimens was measured in three arbitrarily chosen locations. For each location, the average of five readings was recorded as one measurement. Therefore, each mixture is represented by nine measurements of solar reflectance. The average solar reflectance measurements for each mixture are shown in Table 1.

Observations

The lowest solar reflectance for the studied mixtures of 0.34 was produced by one mixture containing a dark gray fly ash (FDG) and one mixture containing one of the darker cements (CXB). This solar reflectance value results in an SRI of about 37. All of the concrete mixtures studied in this report, regardless of constituents, would therefore meet the LEED-NC SS Credit 7.1 paving material requirement or the LEED-NC SS Credit 7.2 steep-sloped

TABLE 1:
MIXTURE PROPORTIONS AND AVERAGE SOLAR REFLECTANCE TEST RESULTS

Mixture designation*	Mixture proportions, lb/yd³					AEA, fl oz/yd³	w/cm	cm/fa	Solar reflectance
			Aggregate						
	Cement	SCM	Fine	Coarse	Water				
CDG-AE-CP-...-...	565	0	1245	1896	225	3.7	0.40	0.45	0.43
CDG-AE-CP-...-SD	261	213	1242	1892	228	3.7	0.48	0.38	0.51
CDG-AE-CP-...-SL	261	213	1242	1892	228	3.7	0.48	0.38	0.47
CDG-AE-CP-FDG-...	381	127	1228	1869	244	2.7	0.48	0.41	0.39
CDG-AM-CP-FDG-...	381	127	1246	1869	244	2.7	0.48	0.41	0.40
CR-AB-CP-...-...	565	0	1258	1895	294	3.7	0.52	0.45	0.36
CR-AE-CP-...-...	565	0	1245	1896	225	3.7	0.40	0.45	0.36
CR-AE-CP-FDG-...	381	127	1228	1869	244	3.7	0.48	0.41	0.41
CR-AM-CL-FDG-...	381	127	1246	1876	252	4.1	0.50	0.41	0.43
CR-AM-CP-FDG-...	381	127	1242	1869	244	3.7	0.48	0.41	0.40
CS-AB-CP-...-...	565	0	1258	1895	299	3.7	0.53	0.45	0.51
CS-AB-CP-...-SD	261	213	1256	1892	272	3.7	0.57	0.38	0.54
CS-AB-CP-...-SL	261	213	1256	1892	228	3.7	0.48	0.38	0.57
CS-AB-CP-FDG-...	381	127	1242	1869	276	3.7	0.54	0.41	0.48
CS-AB-CP-FPB-...	381	127	1242	1869	244	2.7	0.48	0.41	0.57
CS-AE-CL-...-...	565	0	1245	1903	247	3.7	0.44	0.45	0.46
CS-AE-CL-...-SD	261	213	1242	1899	295	3.7	0.62	0.38	0.57
CS-AE-CL-FDG-...	381	127	1228	1876	252	3.7	0.50	0.41	0.41
CS-AE-CP-...-...	565	0	1245	1896	225	3.7	0.40	0.45	0.42
CS-AE-CP-...-SD	261	213	1242	1892	228	3.7	0.48	0.38	0.52
CS-AE-CP-...-SL	261	213	1242	1892	228	4.0	0.48	0.38	0.57
CS-AE-CP-...-SM	261	213	1242	1892	228	2.7	0.48	0.38	0.54
CS-AE-CP-FDG-...	381	127	1228	1869	244	4.0	0.48	0.41	0.34
CS-AE-CP-FLG-...	381	127	1228	1869	244	2.7	0.48	0.41	0.42
CS-AE-CP-FMG-...	381	127	1228	1869	244	3.7	0.48	0.41	0.44
CS-AE-CP-FPB-...	381	127	1228	1869	244	2.7	0.48	0.41	0.47
CS-AE-CP-FVLG-...	381	127	1228	1869	244	3.2	0.48	0.41	0.48
CS-AE-CP-FYB-...	381	127	1228	1869	244	2.7	0.48	0.41	0.46
CS-AL-CP-...-...	565	0	1224	1822	271	3.7	0.48	0.46	0.53
CS-AL-CP-...-SD	261	213	1271	1892	289	3.7	0.61	0.37	0.60
CS-AL-CP-...-SL	261	213	1271	1892	282	3.7	0.59	0.37	0.64
CS-AL-CP-FDG-...	381	127	1255	1869	244	3.7	0.48	0.40	0.46
CS-AL-CP-FPB-...-	381	127	1255	1869	244	2.7	0.48	0.40	0.54
CS-AM-CL-...-...	565	0	1260	1903	274	3.7	0.48	0.45	0.44
CS-AM-CP-...-...	565	0	1258	1895	226	4.0	0.40	0.45	0.52
CS-AM-CP-FDG-...	381	127	1242	1869	244	4.0	0.48	0.41	0.43

TABLE 1 CONTINUED:
MIXTURE PROPORTIONS AND AVERAGE SOLAR REFLECTANCE TEST RESULTS

Mixture designation*	Mixture proportions, lb/yd³					AEA, fl oz/yd³	w/cm	cm/fa	Solar reflectance
			Aggregate						
	Cement	SCM	Fine	Coarse	Water				
CW-AB-CP-...-...	565	0	1254	1888	301	3.7	0.53	0.45	0.59
CW-AE-CP-...-...	565	0	1240	1888	259	3.7	0.46	0.46	0.59
CW-AL-CL-FDG-...	381	127	1228	1876	257	3.7	0.51	0.41	0.44
CW-AL-CP-...-...	565	0	1219	1815	271	3.7	0.48	0.46	0.69
CW-AL-CP-...-SL	261	213	1271	1892	252	3.7	0.53	0.37	0.63
CXB-AE-CP-...-...	565	0	1244	1895	226	3.7	0.40	0.45	0.34
CXB-AE-CP-FDG-...	381	127	1228	1869	244	2.7	0.48	0.41	0.43
CXR-AE-CP...-...	565	0	1244	1895	249	3.7	0.44	0.45	0.37
CXR-AE-CP-FDG-...	381	127	1228	1869	244	2.7	0.48	0.41	0.41

*The mixture designation lists the mixture constituents. See Fig. 1 to 3 for labels.

Note: 1 lb/yd³ = 0.59 kg/m³; 1 fl oz/yd³ = 3.87 mL/m³.

roofing material requirement. The average solar reflectance of all mixtures was 0.47.

Two of the concretes had average solar reflectances of at least 0.64, corresponding to an SRI of at least 78, which meets the requirements for low-sloped roofs in LEED-NC SS 7.2. The first is the mixture designated CS-AL-CP-...-SL, composed of ordinary portland cement, fine aggregate from crushed limestone, Eau Claire coarse aggregate, and light-colored slag cement. The second is CW-AL-CP-...-..., composed of white cement, fine aggregate from crushed limestone, and Eau Claire coarse aggregate.

As shown in Fig. 5, the solar reflectance of the concrete generally increased with increasing solar reflectance of the supplementary cementitious material. The solar reflectances of the ordinary cements (other than the white cement) ranged from 0.36 to 0.47. The solar reflectances of the fly ashes encompassed those of the cements and ranged from 0.28 to 0.55. The solar reflectances of the slag cements ranged from 0.71 to 0.75, exceeding that of both the ordinary cements and fly ashes. Accordingly, the slag cement concretes generally had the highest solar reflectances. The white cement had the highest solar reflectance at 0.87.

The average effect of replacing 45% of the cement in a mixture with slag cement was to increase (lighten) the solar reflectance of the concrete by 0.07. The average effect of replacing 25% of the cement in a mixture with dark gray fly ash was to decrease (darken) the solar reflectance by 0.02.

Fig. 4: The 0.5 ft³ (0.014 m³) pan mixer used to mix concrete for the specimens

REFLECTING ON RESULTS

Our data from 45 concrete mixtures representing exterior concrete flatwork show that the solar reflectance

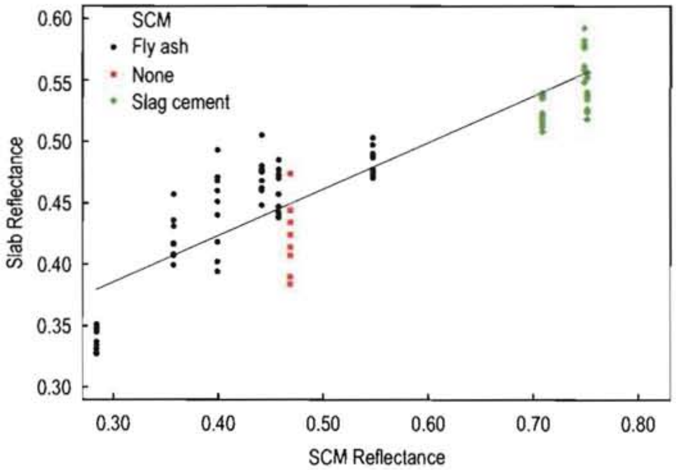

Fig. 5: Effect of solar reflectance of the supplementary cementitious material on the solar reflectance of the concrete mixture. All mixtures contained CS cement, AE fine aggregate, and CP coarse aggregate. Data points for mixture containing no SCM are provided for reference

of the cementitious materials has more effect on the solar reflectance of the concrete than the other constituents. The solar reflectance of the fine aggregate has a small effect on the solar reflectance of the concrete, but the solar reflectance of the coarse aggregate does not have a significant effect. With mixtures including fine aggregate consisting of crushed limestone, average solar reflectances of at least 0.64 (an SRI of at least 78) can be obtained using ordinary portland cement and light-colored slag cement or using white cement alone. Solar reflectances ranged from 0.34 to 0.48 for mixtures consisting of ordinary portland cement and dark gray fly ash.

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Note: Additional information on the ASTM standards discussed in this article can be found at **www.astm.org**.

Selected for reader interest by the editors.

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