ECOSMART™ CONCRETE PROJECT

A Concrete Contribution to the Environment™

GLOBAL ECOLOGY CENTER FOR THE CARNEGIE INSTITUTION OF WASHINGTON

STANFORD UNIVERSITY

THE CURING & MOISTURE EMISSIONS OF CONVENTIONAL vs ECOSMART CONCRETE SLABS

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1.0 EXECUTIVE SUMMARY

The scope of this report is to examine how an EcoSmart™ concrete slab-on-grade is affected by different curing practices and how its moisture emissions compare with that of a conventional concrete mix design. Due to a high degree of client interest in green building research, a controlled test case with various curing regimens was possible within the confines of a relatively small building project.

Our primary finding indicates that an EcoSmart concrete slab can be successfully cured using nothing more than a spray on curing compound without sacrificing strength or moisture emissions performance. This is a significant finding since many practitioners have cited the increased cost and longer schedules required for wet curing as an impediment to the use of EcoSmart concrete.

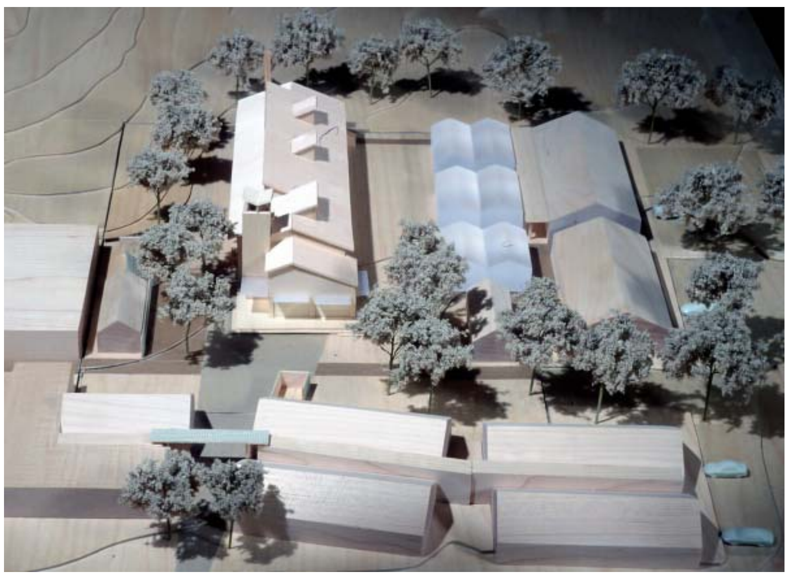

Figure 1: Site model of Global Ecology project.
From left to right: Research Building, Greenhouses, Warehouses

2.0 PROJECT DESCRIPTION

2.1 Project Overview

This study was conducted during Phase I of construction of the new Global Ecology Center for the Carnegie Institution of Washington located at Stanford University. This new research center includes 45 full time researchers and staff located in a main lab/office building, with greenhouses and a warehouse providing support space. The center is dedicated to advancing the understanding of the complex interactions between the Earth's ecosystems up to the scale of the entire planet. It was the scientist's research and understanding of these global ecological interactions, including climate change, which established the sustainable design goals for the project.

Foremost among the sustainable building goals was the minimization of carbon emissions. This was accomplished, first by reducing the building's operating energy, and second by reducing the carbon emissions associated with the building materials. Operating energy was reduced by approximately 60% compared to California's Title 24 energy code by relying on daylighting, natural ventilation, and ultra-low energy radiant slab cooling supplied by a "Night Sky" radiant roof system. Carbon emissions associated with building materials were significantly reduced by using EcoSmart concrete and through the efficient structural design of concrete components.

Phase I of the project included four test slabs for the three greenhouses (one greenhouse had two slabs with an 0.5 m (18") step at the midpoint to accommodate a sloping grade). Three of these slabs were constructed using EcoSmart concrete, the fourth with a standard control mix. The EcoSmart slabs were cured using a 7-day moist cure, a 3-day moist cure, and a conventional spray-on curing compound. The slabs that were moist cured also had a spray-on curing compound applied to them immediately after moisture curing was ceased. The control slab was also cured with a conventional spray-on curing compound. Cylinders and cores were then taken of each slab and tested for strength at 3, 7, 28, and 56 days. Each slab was also tested for moisture emissions at 28 and 56 days. This was done even though these slabs were not scheduled to receive any floor covering to verify moisture emission rates for slabs in Phase II of the construction. The tests and results are described below.

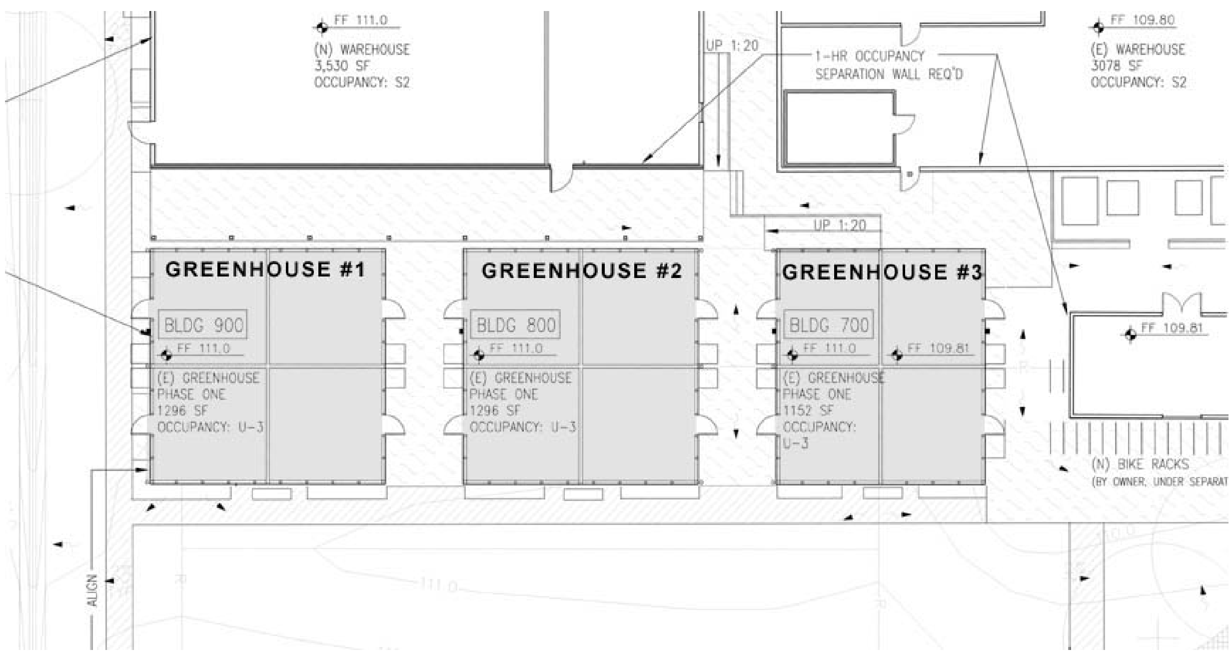

Figure 2: Plan of Greenhouses

2.2 Project Team

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2.3 Project Details

Location:	260 Panama Street, Stanford University Stanford, California
Design:	January 2002 - January 2003
Construction:	March 2003 - June 2003 (Phase 1) June 2003 – January 2004 (Phase 2)
Size:	Research Bldg: 1,010 m^2 (10,890 SF) Greenhouses: 350 m^2 (3,744 SF) Warehouse: 330 m^2 (3,530 SF)

2.4 Project Chronology

The curing and moisture emission studies were undertaken during Phase I construction of the three new research greenhouses. Slabs-on-grade were placed for each greenhouse on April 25, 2003. The temperature ranged from a high of 17^{o}C (62 F) to a nighttime low of 9^{o}C (48 F). A light rain fell on and off throughout the day totaling 2.8 mm (0.11 inches).

Construction on Phase II began in June 2003. EcoSmart concrete was used for foundations, slab-on-grade, lightweight concrete slab on metal deck, topping slabs for radiant tubing, and concrete fill for metal pan stairs. Data for Phase II is not yet complete but will be added to this report when it becomes available.

3.0 USE OF ECOSMART CONCRETE

3.1 Goals

In the San Francisco Bay Area EcoSmart concrete has typically been specified to require moist curing. This requirement has often been cited by contractors as a significant cost premium and a major impediment to the use of EcoSmart concrete for slabs. This is particularly true for slabs that require construction access soon after placement. Conventional concrete, with very few exceptions, is being cured with the application of a spray-on curing compound, which allows contractors quick access to the slab, often the day after placement, with minimal impact on schedule. This study compares the rate of strength development of EcoSmart concrete slabs cured with a curing compound vs 3- and 7-day moist curing.

Additionally, this study examines the rate of moisture emission from EcoSmart concrete. Over the last decade, building projects in California have experienced a dramatic increase in flooring failures. These have been with impervious floor covering such as sheet vinyl, linoleum, VCT, carpet with PVC or other impervious backing, which together comprise the majority of floor covering in our region. Failure is generally thought to be due to the switch to lower VOC adhesives that are less able to resist the moisture emissions from fresh concrete. All flooring manufacturers now require the slab meet a specific moisture emissions level based on a standard calcium chloride test. The slabs very frequently fail this test, which voids the warranty, delays the job, or requires the application of a floor sealer compound. Many architects now specify the floor sealer as standard practice to avoid the problem, but at a major expense (these costs vary widely depending on level of moisture emission and type of floor sealer).

Our thesis is that there are three functions affecting the emission rate and the flooring failures: 1. the amount of water in the initial concrete mix, 2. the permeability of concrete, and 3. the alkalinity of the evaporate which effects the adhesives (a number of the floor seal product manufacturers claim their products work primarily by reducing this alkalinity). We believe EcoSmart concrete will use less water in the initial mix, be less permeable, and reduce the alkalinity of the evaporate, possibly allowing the elimination of the floor sealer. This would be a major impetus to the use EcoSmart concrete on floor slabs.

Figure 3: Greenhouses with Polycarbonate Panels

3.2 Part One: The Effect of Various Curing Regimens on EcoSmart Concrete Slabs

3.2.1 Concrete Placement

The test slabs included two greenhouse slabs at 11 m x 11 m (36' x 36') and two at 5.5 m x 11 m (18' x36'). The slabs were 10 cm (4") thick and placed directly on a 10 mil polyethylene vapor barrier over engineered fill. The concrete was placed by pump between 7:00 AM and 12 noon, then screened and floated. The slabs were covered on several occasions to protect them from a light rain. The slabs were power and hand floated and steel trowel finished followed by a light broom finish. Finishing of the control slab proceeded somewhat slower than usual due to the rain conditions. The final EcoSmart concrete slabs were not ready to finish until the following day due to the rain and the resulting additional moisture on the surface of the slab. The finishers reported a number of difficulties in finishing the slab that were directly related to the amount of rain on the day of pour and partial finishing the following day.

Immediately after finishing, the spray-on curing compound was applied to the control slab and one EcoSmart concrete slab. Extra care was taken that the curing compound was applied in strict accordance to the manufacturer's recommendations, including that the total amount of curing compound applied for the given square footage was correct and that two overlapping passes were made at right angles to one another. The curing compound application was witnessed and verified by the testing agency. The remaining two Ecosmart concrete slabs were covered immediately with polyethylene, which was left on overnight and then with a curing paper the next day (a laminate of polyethylene and open cell foam to hold water). The curing paper was moistened daily for the duration of the moist curing regiment, it was then removed and the slab was covered with the spray-on-curing compound.

The resulting slabs are of average quality with minor cracking in some areas, the control slab exhibited slightly more cracking than the EcoSmart slabs. The General Contractor placed and finished the concrete. Their finishers said that the rainy weather was the biggest challenge affecting the work.

3.2.2 Curing Regimen

To understand the effect of varying curing regimens, strength gain of EcoSmart and conventional concrete was compared as follows:

Table 1: Curing Regimens

Regimen	**Concrete Mix Design**	**Moist Curing**	**Curing Compound**	**Concrete Quantity**
A	Ecosmart	None	Immediate	15.7 m^3 (20.5 CY)
B		3 days	after 3 days	7.6 m^3 (9.9 CY)
C		7 days	after 7 days	7.6 m^3 (9.9 CY)
D	Control Mix	None	Immediate	15.7 m^3 (20.5 CY)

3.2.3 Concrete Mixes and Curing Compound

The specified compressive strength for the slabs was 28 MPa (4,000 psi). The two concrete mix designs are tabulated in Table 2. The Ecosmart concrete was made with 55% Class F fly ash and Type I/II cement, reducing cement content by 44% from the conventional mix. The water to cementitious materials ratio was 0.33 and a high range water reducer was added to the mix. This mix was designed to achieve the specified strength in 56 days. The conventional mix contained the typical 15% fly ash and had water to cementitious materials ratio of 0.49. The curing compound used was a water emulsion acrylic (W.R. Meadows “VOCOMP-25”) applied with a manual sprayer in accordance with the manufacturer’s recommendations.

Table 2: Concrete Mix Designs (kg/m3 (lbs/CY))

	EcoSmart Mix		Control Mix	
Design Strength	28 MPa	(4,000 psi)	28 MPa	(4,000 psi)
Cement Type I/II	160 kg	(270 lbs)	284 kg	(479 lbs)
Fly Ash Class F	195 kg	(330 lbs)	50 kg	(85 lbs)
Water	119 kg	(200 lbs)	163 kg	(275 lbs)
W/C+F ratio	0.33		0.49	
20 mm (3/4") Gravel	875 kg	(1475 lbs)	1038 kg	(1750 lbs)
10 mm (3/8") Gravel	281 kg	(475 lbs)	0 kg	(0 lbs)
Sand	781 kg	(1317 lbs)	843 kg	(1421 lbs)
Adwa Flow HRWR	1.2 L	(30 oz)	0 L	(0 oz)
WRDA-4	0.7 L	(18 oz)	0.7 L	(17 oz)
Total	2413 kg	(4067 lbs)	2379 kg	(4010 lbs)

3.2.4 Compressive Strength Data

The in-situ strength development of the concrete was determined by extracting and testing 8 cm (3”) diameter cores from the slabs. Cores were extracted and tested on the day of the test. In addition, companion 15 cm x 30 cm (6” x 12”) cylinders were also cast on the day of the placement. The cylinders were moist cured in the laboratory and tested in accordance with ASTM C39 procedures.

The compressive strength data of the cores is tabulated in Table 3. The reported core compressive strengths are average of two tests. Detailed strength data is provided in Appendix A. The strength versus age data is plotted in Figure 4. No adjustments have been made to the strengths as allowed by ACI (core strength data is more than 85% of companion cylinders manufactured and tested in accordance with ASTM C39).

The compressive strength test results of the cylinders are also tabulated in Table 3.

Table 3: Compressive Strength Results (MPa (psi))

	EcoSmart Concrete				Conventional Concrete	
	Cores			Cylinder	Core	Cylinder
	No moist cure	3-day moist cure	7-day moist cure		No moist cure	
3 days	13.7 (1980)	9.7 (1410)	9.8 (1420)	6.1 (890)	17.7 (2560)	14.7 (2130)
7 days	14.4 (2240)	13.6 (1970)	17.3 (2515)	15.0 (2170)	23.9 (3460)	22.1 (3200)
28 days	25.0 (3620)	20.9 (3030)	29.1 (4220)	25.9 (3760)	32.5 (4720)	35.1 (5090)
56 days	33.2 (4810)	33.1 (4800)	37.1 (5380)	37.1 (5380)	35.8 (5190)	38.9 (5640)

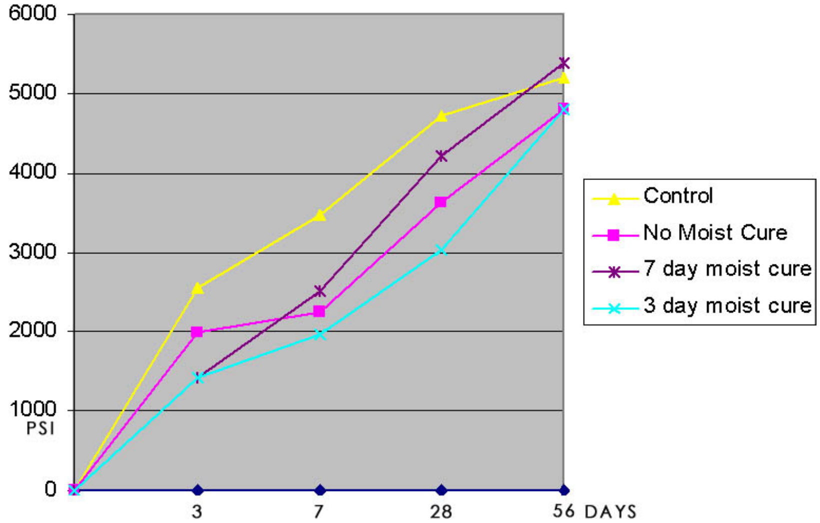

Figure 4: Core data – Strength vs. Age

3.2.5 Discussion

Comparing the strength gain over time provided in Table 3 and Figure 4 for the three EcoSmart slabs, the effect of the 7-day moist curing is apparent at 7 days and beyond. The slab with 7 days of moist curing has higher strength at 7, 28 and 56 days compared to slabs with shorter or no moist curing. However, the following equally significant findings indicate that the spray-on curing regimen provided an effective means of curing EcoSmart concrete:

- The EcoSmart slab with no moist curing exceeded the specified strength at 56 days.
- All three EcoSmart slabs continued to gain strength at approximately the same rate. Thus, the curing compound allowed for continued hydration over time.

The following comparisons of core compressive strengths with companion moist cured cylinders provides additional evidence that the curing compound was effective in curing EcoSmart slabs:

- At 56 days, all three EcoSmart slabs achieved strengths comparable to the cylinders.
- At 56 days, the core compressive strengths of the EcoSmart slab (with no moist curing) and conventional concrete slab, also with no moist curing, were 89% and 92% respectively of the cylinder strengths. This is additional confirmation that the EcoSmart slab cured in a manner similar to the conventional concrete.

These results indicate that a spray-on curing compound applied in strict adherence to the manufacturers directions can be an effective curing regime for EcoSmart concrete. We believe this will encourage the more widespread use of EcoSmart concrete for concrete slabs.

3.3 Part Two: Moisture Emissions of EcoSmart Concrete Slabs

The moisture emissions from EcoSmart concrete slabs are of interest for applications where impervious vinyl, linoleum, rubber, PVC backed carpet or equivalent flooring membranes have to be applied on a concrete floor slab. Manufacturers now require that the slab must meet strict moisture emissions limits or it will void the warranty. No party involved in the construction process is usually willing to take the risk of the flooring failure so many architects now specify a moisture floor sealer as standard practice. The cost of the floor sealer increases as the rate of moisture emission increases and varies widely. If the use of EcoSmart concrete can reduce the amount of moisture leaving the slab, significant cost savings can be achieved.

One inherent advantage of EcoSmart concrete is the lower water content in the mix design compared to conventional concrete (in our case, 119 vs 163 kg/m^3 (200 vs 275 lbs/CY)). Starting with a lower water content, these slabs can dry faster than conventional concrete slabs and allow faster application of floor coverings that require low moisture emissions.

Moisture emission tests were performed on the four greenhouse slabs described above. The tests used a standard calcium chloride test and were performed in accordance with procedures outlined in ASTM F1869. Moisture emission data obtained at 28 and 56 days after the slabs were placed is tabulated in Table 4. The reported emissions are single tests performed on the slabs. Typical moisture emission rates required by flooring manufacturers in California before they will warrant the installation vary from 1.5 to 2.4 kg/100 m^2/24 hrs (3 to 5 lbs/1,000 sf/24 hrs).

Table 4: Moisture Emissions (kg/100 m2/24 hrs (lbs/1,000 sf/24 hrs))

	EcoSmart Mix			Conventional Mix
	No Moist Cure	3 day moist cure	7 day moist cure	No moist cure
28 days	4.6 (9.5)	6.5 (13.4)	6.1 (12.4)	5.2 (10.7)
56 days	3.2 (6.5)	3.9 (8.0)	5.3 (10.9)	4.7 (9.7)

3.3.1 Discussion

Tests had to be terminated at two months since the greenhouses were being used and the slabs were beginning to be exposed to water.

The following findings were true at 28 days after the slabs were placed:

- Moisture emission from the EcoSmart slabs that were moist cured was higher than the moisture emission from the two slabs that were not moist cured.
- The lowest moisture emission was from the EcoSmart slab that was not moist cured.

The following findings were true at approximately two months after the slabs were placed:

- The EcoSmart slab that was moist cured for 7 days had a higher moisture emission than the control; the other two EcoSmart slabs had lower moisture emissions as compared to the control slab.
- Comparing the moisture emission data of the two slabs that were not moist cured (cured only with curing compound), EcoSmart concrete had a 30% lower moisture emission as

compared to the control mix. This result is in line with expectations, since the amount of mix water in the EcoSmart concrete was approximately 35% lower than the mix water in the conventional concrete.

- The EcoSmart slabs moist cured for 3 days and cured with a curing compound saw reductions in moisture emission of 40 and 32% respectively between 28 and 59 days. The reduction in moisture emission for the control slab in the same time period was only 9%.

The above findings are consistent with expectations. The control mix has approximately 69 kg/m^3 (117 lbs/CY) excess moisture as compared to 19 kg/m^3 (32 lbs/CY) for the EcoSmart mix (assuming a 0.28 water to cementitious materials ratio for complete hydration). The approximately 350% excess moisture in the control mix as compared to the EcoSmart mix will take a lot longer to be released from the concrete. Although we were not able to continue the test to find how long until reaching the Manufacturer's approved moisture emission rates of 1.5 to 2.4 kg/100 m^2/24 hrs (3 to 5 lbs/1,000 sf/24 hrs), the data trend for the EcoSmart mix suggest that in approximately one additional month the emission rate would be within the permissible range for some floor coverings.

Figure 5: Moist curing of EcoSmart concrete slab

4.0 CONCLUSIONS AND RECOMMENDATIONS

Curing compound, when applied in strict accordance with manufacturer's recommendations, can be used to cure EcoSmart concrete slabs with no adverse effects on strength. Further studies are recommended to confirm our findings. This can be a significant benefit for projects that need immediate access to the slab to continue work or where the use of moist curing adds significant cost to a project. We also suggest that for slab-on-grade applications, where moisture emission and early strength are not a consideration, EcoSmart mixes with higher water and cement content be used. Increasing the water (water to cementitious materials ratio of approximately 0.40) and cement content (to 50%) will result in more forgiving mixes, in particular for slabs-on-grade, which should cure adequately with the proper and timely application of a curing compound.

The moisture emissions of EcoSmart concrete compared to a conventional concrete will provide lower moisture emissions at any age when only a curing compound is used. For slabs that require moisture emission control, an EcoSmart mix with comparable strength and workability will always have less water than a conventional mix, and will therefore dry faster. Further studies are recommended to verify if this warrants the elimination of floor sealer products from standard specifications. But based on the data presented here that show both lower moisture emissions rates and faster rates of drying, this is very promising possibility that could result in significant cost savings.