2006-1157: GREENCRETE: A PROJECT ON ENVIRONMENTALLY FRIENDLY CONCRETE

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Greencrete: A Project on Environmentally Friendly Concrete

Abstract

Students are tested in their knowledge of "green" concrete through a course project that requires the development of Greencrete. Greencrete is similar to a commercially available product called Quikcrete 5000©. Quikcrete 5000© is a ready-mix bag of concrete available in 80 pound bags that will attain a compressive strength of 5000 psi by 28 days of age. Each bag consists of cement, gravel, and sand. For the project, students are divided into groups of 4 or 5, and each group must develop their own Greencrete mixture. Each mixture must contain slag cement and fly ash, both recycled materials. Their mixture can not cost more than Quikcrete 5000© and must also have a 28 day compressive strength greater than 5000 psi. Students are also required to research yearly sales of Quickcrete 5000©, and determine how the use of their product, Greencrete, would benefit the environment.

Introduction

Protecting the environment is becoming a ubiquitous mandate and, more frequently, civil engineers will be called to meet infrastructure demands in ways that are less harmful to the environment and sustainable into the future. One way to meet such demands is by producing and using "green" or environmentally friendly concrete. Supplementary cementing materials (SCMs) such as fly ash, silica fume, and slag cement are frequently employed in concrete mixtures for performance and economic reasons. However, there are environmental reasons for incorporating SCMs. SCMs are mainly industrial byproducts that, in most cases, would otherwise be headed for landfill disposal but now are used to improve concrete performance. Also, the use SCMs extend the current supply of cement. Cement production is energy intensive and emits carbon dioxide (CO_2), a greenhouse gas. Reducing the amount of cement in a concrete mixture through the use of SCMs also benefits the environment by decreasing the amount of energy required to produce a concrete structure.

Background

Slag cement and fly ash are two industrial byproducts that have cementitious properties when introduced into the proper environment. These waste products are typically disposed of in landfills, but many state departments of transportations (DOTs) are allowing the use of slag cement and fly ash as building or construction materials for use in transportation structures.

Fly ash is waste from coal-burning energy plants. Slag cement is created from fluxes, lime-based inorganic sources, and iron ore combined and heated to a molten state in the production of iron. The fluxes absorb the impurities from the iron ore and are rich in lime, silica, and alumina. When the slag is rapidly cooled by water, glassy granules are formed and then ground to cement sized particles. Both fly ash and slag cement have the proper chemistry to achieve cementitious properties. The chemical compositions for the slag cement and fly ash used in the project are shown Table 1.

Table 1. Chemical Composition of the Fly Ash and Slag Cement.

Compounds	Fly Ash	Slag Cement
SiO_2	34.39	32.00
Al_2O_3	20.26	12.00
Fe_2O_3	6.17	0.60
CaO	25.71	42.00
MgO	5.95	9.00
SO_3	1.44	0.15

Slag cement and fly ash have been shown to improve long-term strength and durability. These materials improve the characteristics of concrete by reacting with products formed during the hydration of cement. Equations 1 and 2 show the hydration reactions of portland cement. Calcium silicate hydrate (C-S-H) is the major contributor to concrete strength. SCMs such as slag cement and fly ash contain amorphous silica (S) which reacts (Equation 3) with calcium hydroxide (CH) to form additional C-S-H thereby improving strength. The equations shown below are in ceramic notation.

$$2C_3S + 11H \rightarrow C\text{-}S\text{-}H + 3CH \quad (1)$$

$$2C_2S + 9H \rightarrow C\text{-}S\text{-}H + CH \quad (2)$$

$$CH + S + H \rightarrow C\text{-}S\text{-}H \quad (3)$$

In addition to improving hardened concrete properties, SCMs are also used to produce "green" structures. The force behind the green movement is to design and build structures that are more environmentally friendly and conservative. Buildings can be certified as a Leadership in Energy and Environmental Design (LEED) building. According to the United States Green Building Council's website, the purpose of LEED is to standardize the idea of a "green building," promote whole-building design practices, recognize the environmental leaders, stimulate competition, and raise awareness of the benefits of conservation.[1] Certification is based on a system of credit points for different aspects of design, spatial and material, and construction practices. LEED certification is awarded at a total of 26 points and levels of recognition are given for 33 points (silver), 39 points (gold), and 52 points (platinum).[1] The criteria for points include: site selection, public transportation access, reducing heat islands, renewable energy sources, reuse of existing materials, use of recycled materials such as slag cement and fly ash, and innovative interior design. The LEED system defines sustainability "as development that meets the needs of the present without compromising the ability of future generations to meet their own needs."[1]

Concrete can be used in several ways in order to increase the LEED project points. Portland cement concrete can be used instead of asphalt to reduce heat islands. The reduction of the heat island is based on the increased solar reflectance of the materials used for large areas. The solar reflectance is the amount of radiation reflected back from a surface compared to the amount shone on the material. Concrete generally has a solar reflectance of approximately 0.35 and "white" concrete can have a value of 0.7 to 0.8.[1] Slag cement will also increase the "whiteness" of the concrete when added in significant amounts. Asphalt, on the other hand, will generally have a reflectance of less than 0.2. Another LEED criteria for points states, "specify a minimum of 25% of building materials that contain in aggregate a minimum weighted average of 20% post-consumer recycled content material, or, a minimum weighted average of 40% post-industrial recycled content material."[1] SCMs, including slag cement and fly ash, are considered post-industrial.

The use of waste materials is also important for more reasons than the construction benefits. In 2002, 30% of the fly ash produced yearly was used in various construction-related applications with 10% used in concrete.[2] Unless some recycling occurs, these waste products end up in landfills. Over 250 million tons of fly ash and over 18 million tons of slag cement are produced every year in the United States.[3,4] The American Concrete Institute (ACI) and the Environmental Protection Agency (EPA) encourage recycling by supporting the Resource Conversation and Recovery Act (RCRA) and recycling in concrete. The RCRA requires agencies under federal funding to purchase products with the highest percentages of recovered materials practicable.

The annual global production of concrete was about 5 billion tons in 1997 according to Penttala.[5] Penttala also mentions the greatest threats for the earth's future as: population growth, global temperature rise, polluting of the air, water and soil, and the availability of fresh water resources.[5] Because of the effects of the industrial revolution and the use of fossil fuels, the level of CO_2 in the air has increased by as much as 25% in 200 years.[6] Increasing levels of CO_2 have helped increase the amount of greenhouse gases. The greenhouse gases deplete layers of the ozone that prevents harmful radiation from reaching the earth's surface and that also prevents heat from escaping back into the atmosphere. Sustainable development is needed to ensure natural resources and the function of future generations. Manufacturing cement involves burning raw materials and the production of CO_2. About 0.56 ton of CO_2 per ton of cement is released during cement production and about 0.35 ton of CO_2 is released in the fuel.[6] CO_2 production can be reduced by about 0.5 tons per ton of cementitious material if SCMs are used to replace 50% of the cement.[6]

The use of SCMs will also extend our current supply of cement. In a Flash Report of *The Monitor*, the Portland Cement Association (PCA) culminated reports of a cement shortage in the United States. Although concrete use is encouraged by the industry, the lack of supply could turn industries away from the material. The report sites two major reasons for the increase in demand for cement: the reduction in the quantity of imported cement and the demand from the United States economy for construction materials.[7] The use of waste products, such as slag cement and fly ash, would extend the current supply of cement.

Studies have also shown that the increase in construction speed has decreased the effectiveness of concrete structures. More often mixtures contain early strength admixtures and greater concentrations of highly reactive portland cement.[8] Although these increases allow for increased speed of construction, they also create higher thermal and drying shrinkage needing, more preventative attention and costing more money in repair.[8] Materials such as fly ash and slag cement have lower heat of hydration, and thus preventing shrinkage cracking, increasing durability and reducing permeability. These properties are appealing in concrete because they prevent premature repair and possible failure.

Structural Materials

Structural Materials is a sophomore level course that is taught in most civil engineering curriculum. The course is taught in the fall and spring semesters and generally there are 20 students enrolled. Two 50 minute lectures per week and one 2 hour and 50 minute laboratory make up the course. As it is presently taught, concrete makes up approximately 60 percent of the class. The remaining 40 percent is divided between steel and wood. The laboratory exercises also focus on mixing and testing concrete.

Project Requirements

Depending on the size of the class, groups of 4 to 5 students are formed (typically the same as their laboratory groups). The groups are allowed to use any material in the civil engineering laboratory for their Greencrete mixture. The available materials, costs, and properties are shown below in Table 2.

Table 2. Available Materials and Properties.

Material	Cost/ton	Specific Gravity	Absorption Capacity (%)
Cement	$95	3.15	-
Slag Cement	$85	2.90	-
Fly Ash (Class C)	$35	2.60	-
Coarse Aggregate	$26	2.68	0.38
Fine Aggregate	$26	2.60	0.48

There are basically three major requirements in the project. First, the students' Greencrete 5000 mixture must attain a compressive strength of 5000 psi by 28 days. Second, their Greencrete mixture must contain at least one SCM. Third, their mixture must cost less than a bag of Quikrete 5000©. In addition to the three major project requirements listed above, each group must;

1. Provide detailed instructions for mixing their Greencrete mixture,
2. Research the total sales of Quikrete 5000© for the previous year,
3. Determine how much fly ash and slag cement is disposed of in landfills each year,

4. Determine how much cement would be saved if their Greencrete mixture replaced Quikrete 5000© with the same number of sales.
5. Summarize their findings into a 5 page report which is due the last day of class.

Each group is furnished two bags of Quikrete 5000©. In one laboratory session during the semester, each group, with their first bag of Quikrete 5000©, must provide a reasonable estimate of the quantities constituent materials. In past semesters, students passed the Quikrete 5000© through a series of sieves to separate the materials. Next, with their second bag, the groups mix their Quikrete 5000© in a wheelbarrow according to the instructions on the bag. Each group must document the quantity of water added and add that same amount to their Greencrete Mixture. Finally, the students schedule a time with the professor to batch their Greencrete mixture. Students cast six, 4 by 8 in. cylinders, from each batch to test at 14 and 28 days of age (3 cylinders tested at each age). Shown Figures 1 through 3 are students mixing their Quikrete 5000© and Greencrete mixtures.

Figure 1. Students Mixing Quikrete.

Figure 2. Greencrete Mixture before Mixing.


Figure 3. Students Mixing Their Greencrete.

Results

Each group's Greencrete mixture proportion and material costs are summarized below in Table 3. The costs shown below are only material costs and are based on material costs for the local area. Also shown in Table 3 is the average mixture proportion determined by the students for Quikrete 5000©. Once again, the students determined the Quikrete 5000© proportions by passing the 80 lb. bag of Quikrete 5000© through a series of sieves to separate the materials. The Quikrete 5000© proportions shown below are rough estimates and are shown only for comparison purposes.

The Greencrete mixture proportions varied amongst the groups. Cement contents ranged from 12.6 to 19.9 lbs. Four of the five groups chose to use both slag cement and fly ash, but the quantities of SCMs varied amongst the groups. Coarse aggregate contents ranged from 21.3 to 37.0 lbs. Fine aggregate contents ranged from 4.4 to 32.0 lbs.

Also shown in Table 3 is the average estimated material cost for all Quikrete 5000© mixtures and for the individual Greencrete mixtures. The Quikrete 5000© material costs, based on the student estimates, ranged from $1.74 to $1.92 with an average of $1.82. The material costs for 4 of the 5 Greencrete mixtures were less than the average Quikrete 5000© cost with the only exception being Group 1.

Table 3. Greencrete Mixtures Proportions.

Materials (lb.)[3]	Quikrete 5000©	Laboratory Groups				
		1	2	3	4	5
Cement (lb.)	22.9	14.7	19.9	17.3	12.6	13.0
Slag Cement (lb.)	-	6.3	1.4	1.9	2.4	5.0
Fly Ash (lb.)	-	-	7.1	3.9	4.4	5.0
Coarse Agg. (lb.)	24.5	25.0	21.3	25.2	37.0	25.0
Fine Agg. (lb.)	31.5	32.0	30.0	30.9	4.4	31.8
Water[1] (lb.)	-	6.3	10.2	6.0	-	7.9
Material Costs	$1.82	$1.85	$1.80	$1.70	$1.32	$1.66

1. Water is added by the buyer and is not included in material costs.
2. Group 4 did not report the quantity of water added.
3. Weights are the total quantity of material used in each mixture.

Shown below in Table 4 is the 14 day compressive strength data. The compressive strengths were measured in a 400 kip Forney compression machine. Originally the project required 28 days strengths greater than 5000 psi, but by 14 days of age, all Greencrete mixtures had achieved their targeted 28 day strength. It is expected that 3 of the 4 Quikrete mixtures would reach 5000 psi by 28 days, with the exception being Group 5's mixture. The low strength reported by Group 5 may have been due to additional water in their mixture or their Quikrete may not have been mixed properly.

Table 4. Compressive Strength Data (psi).

Mixture	14 Day Compressive Strength (psi) for Each Laboratory Group				
	1	2	3	4	5
Quikrete	4870	4260	4980	-	3020
Greencrete	6010	6520	7440	-	5230

1. Group 4 did not report their strength results.

Conclusions

Engineers are now living in an age where cost, performance, aesthetics, and availability are not the only factors in choosing a structural material for a project. Today's and tomorrow's engineers are also choosing materials that are less harmful and that also benefit the environment.

Greencrete Project introduced this concept of "green" materials to the students. Other benefits of the project include;

1. Increasing the students' familiarity with the library and the technical resources that are offered there.
2. Introducing students to the business side of engineering. The students must produce a product that meets engineering specifications, but also produce a product that is economical.

There are some changes that will be made in future Greencrete Projects. For the next project, the reports must conform to the guidelines of a technical journal. Group presentations to their peers will also be incorporated in the future. Finally, the project will be assigned early in the semester so students have adequate time to research Quikrete 5000© sales and do trial batching and testing if so desired.

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