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A Preliminary Assessment of Dried Algal Biomass as a Filler Material in Concrete

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Abstract

Algae is grown and harvested in an ecotechnology terms the Algal Turf Scrubber™ as a method for removing nutrients (primarily nitrogen and phosphorus) from polluted waters. Past studies have demonstrated that the harvested algae often has a high mineral ash content (60 – 80% of dry mass), derived from suspended sediments that adhere to the algal cells and from the silica shells of diatoms (Bacillariophyta). Because of the high ash content, dried algae was tested as a potential additive in concrete. Standard strength testing was done on mixes of commercially available cement and dried algae. Strength of concrete was found to be inversely proportional to dry algal content. Mixes with 1 - 5% dried algae were similar to the control of 0% dried algae (100% cement). Therefore, nutrient pollutants in dried algae may be able to be sequestered in concrete, especially if the concrete is used in non-load bearing applications.

™ The Algal Turf Scrubber is trademarked to the Hydromentia Company of Ocala, FL.

Introduction

The potential of controlled algae growth for removing nutrients from eutrophic waters is being studied as a possible best management practice in the Chesapeake Bay watershed and elsewhere. The algae take up nutrients during their growth and when they are harvested the nutrients are removed from the source water, thereby improving water quality. The algal turf scrubber (ATS) (Adey and Loveland 2007, Adey et al. 2011) is one example of this form of ecotechnology which utilizes fast-growing filamentous attached algae (e. g., periphyton) to treat polluted rivers, lakes and estuaries. The ATS has been demonstrated to be effective at nutrient removal but the challenge now is to find economic uses for the harvested algae biomass that contains the nutrients. Several byproduct uses of harvested algae, such as a feedstock for biofuels and as an animal feed, are being tested. However, one of the problems with microalgae grown on natural waters is that they often have a high inorganic ash content from sediments that are filtered out of the source water as it passes through the algal raceway and from the silica shells of diatom algae (Bacillariophyta) that can dominate the periphyton community of the ATS. This high ash content limits certain bioproduct uses of harvested algae, which require a higher organic content and lower ash content.

In this study we examine the use of harvested algae as a filler additive for concrete production. In this potential application the high ash content of the algae is actually a positive aspect due to the mineral-basis of concrete. Filler materials are often added to concrete mixtures in relatively small amounts (Winter et al. 1964). In some cases these fillers are waste materials, such as palm oil waste (Shafigh et al. 2014) or used tire rubber (Thomas and Gupta 2015), which makes the production of concrete a kind of waste disposal option. Furthermore, new forms of "green concrete" are being developed for absorbing and sequestering CO2 as a contribution towards mitigating greenhouse gas emissions (Rosenwald. 2011, Bradley 2010, Chang 2014). This kind of research is a creative form of material science that combines traditional civil engineering with aspects of environmental science and technology (Kibert 2013). Here we examine the potential of a very literal form of "green concrete", a mixture of dried algae plus concrete, as an economic option for sequestering nutrient elements that have been removed from polluted waters.

Methods

Algae from an ATS operated at the Port of Baltimore was used in this study. This algae was grown with brackish water (salinity 5 – 10) from the Patapsco River in Baltimore harbor. The dominant algae were a filamentous diatom of the genus Melosira. The Green alga, genus Ulva, was a subdominant taxa in the turf community. The harvested algal biomass from the ATS was air-dried and then processed into a fine powder in a blender. The ash content of the algae averaged 64% of the total biomass. A detailed listing of the chemical composition of one sample of the algae is included as Appendix 1.

Powdered algae was combined with a commercially available concrete (trade name: Sakrete, which meets the ASTM C387 standard) to create a gradient of experimental mixtures. The volumes of the dry materials were measured and they were mixed with water and stirred to a uniform consistency. The mixtures were then poured into standard plastic testing cylinders in accordance with ASTM C31, the standard practice for making and curing concrete samples. These cylinders were 4" in diameter by 8" in height with a volume of approximately 100 cubic inches. The concrete mixes were packed in the cylinders by using a 3/8" diameter tamping rod.

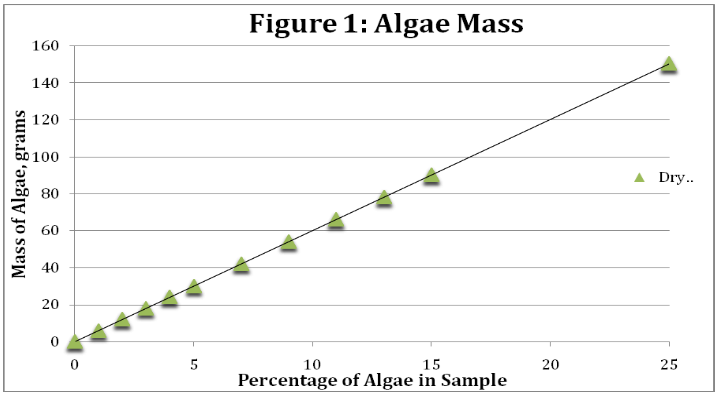
For initial testing, sample mixes ranged from 0% (e.g., the control) to 25% dry algae in terms of volume. These samples were cured for 28 days and then they were weighed using a laboratory digital balance. The strength of each sample was tested by using a 150 ton Enerial hydraulic press located in the Environmental Science and Technology Departmental Project Development Center at the University of Maryland. The hydraulic press added constant and increasing pressure until the concrete cylinder was broken. The amount of pressure applied at the breakage point was recorded on a PSI gauge on the press. This initial round of testing was carried out in order to narrow the range of potentially viable mixes of dry algae and concrete to be used in the second round of testing that utilized more accurate equipment.

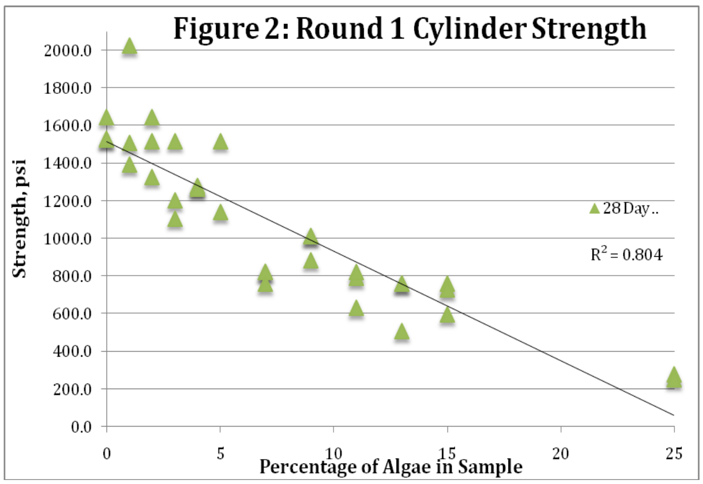
For a second round of testing concrete mixes ranging from 0% to 9% dry algae volume were prepared. There were six replicates for each sample mixture, with three replicates cured for 7 day strength testing and three replicates cured for 28 day strength testing. These cylinders were evaluated by using a compression testing machine located in the Civil and Environmental Department at the University of Maryland, College Park. This machine applied increasing pressure to each cylinder until the concrete was cracked. The data were converted into compression strength based on the cylinder's diameter.

Results

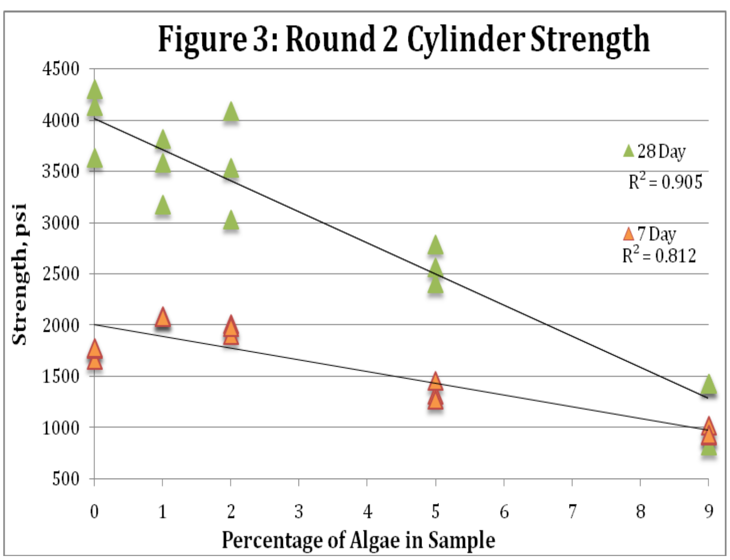
The mass of algae used in each cylinder is shown in Figure 1 after curing for 28 days during the first round of testing. A linear trend was found, represented by the equation y=6.013x + 3E-14. The positive direction of the trend indicates that mass of algae is directly related to the volumetric percentage of algae used in the mix.

During the first round of strength testing a hydraulic press was used to estimate the strength of different mixtures with up to 25 percent algae after a 28-day cure. The cylinder strength for this round of testing is shown in Figure 2. A linear trend was found, represented by the equation y=-58.156x +1513.4. The negative slope of this trend indicates that strength of the concrete decreases as the percentage of algae increases.





The second round of strength testing was completed with more precise equipment. The results from these cylinders are shown in Figure 3. A decreasing trend was found for both the 7-day and the 28-day curing times. In both cases there is a linear trend. The regression equation for the 28 day trend is y=-302.59x + 4009.8 and the regression equation for the 7 day trend is y=-114.96x + 2008.1. The negative slopes indicate that the strength of the concrete decreases as the percentage of algae in the mix increases.



Discussion

The results of this study demonstrate that increasing dry algal content leads to decreasing quality of the concrete mix, in terms of its load bearing strength. The organic content of the algal biomass used in this study, which is comparatively low at about 30-40 percent of the total algal biomass, may be the factor that effects the curing processes of the concrete. Under optimal conditions use of a filler material in the concrete mix should lead to increased performance, but dried algae does not seem to match with this goal. Thus, only small amounts of dried algae can be used as a filler for concrete for most practical uses in order to take advantage of the nutrient sequestration concept. Although more testing is needed, algal-based concrete will have limited uses. Based on the regression curves presented here, only mixes with 5 percent or less dry algae may be appropriate for use. These mixes had strength characteristics similar to the control group of cylinders that had no dried algae added. However, because the commercial concrete used in this study probably already contains filler materials, it may be possible to increase the percentage contribution of dry algae if an initial concrete without pre-made filler material was used in the mixes.

Even though the uses of algal-based concrete are limited, concrete is one of the most common materials produced and used by humans (Courland 2011, Palley 2010) so there may be possible applications. Possible used for algal-based concrete might include sidewalks, landscaping elements and ornaments, and barriers used in traffic control (e. g., "Jersey barriers"), along with other concrete features that do not have significant load-bearing requirements. To illustrate the nutrient sequestration potential of this kind of application of algal-based concrete, the nutrient content of a typical Jersey barrier can be estimated as follows. Assuming a mixture of 2.5% dry algae and 97.5% concrete and an algal density of 0.365 grams dry weight/ml found in this study, the mass of algae in a typical concrete Jersey barrier (2' wide at the base, 2 2/3' high and 8' long, see Appendix 2 for a diagram) would be 5656 grams. Assuming that the algal biomass is composed of 2% nitrogen as has been found in multiple field studies, the total mass of nitrogen sequestered in a Jersey barrier made of algal-based concrete would be 113 grams. Since hundreds of Jersey barriers can be used in a typical highway construction project, the mass of nutrients that can be sequestered in this way can be significant. Therefore, the creation of algal-based concrete from algae harvested from ecotechnologies such as the algal turf scrubber, may be a viable end-use option of restoration plans to improve water quality of the Chesapeake Bay and other polluted water bodies.

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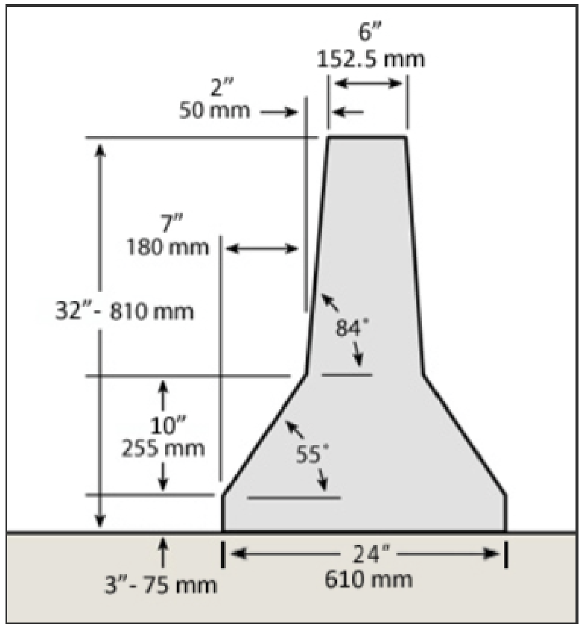
APPENDICES

Appendix 1. Chemical composition of microalgae from the Port of Baltimore ATS. Data are % of dry weight except for micronutrients which are in ppm. Analyses were done by the Equi-Analytical Laboratory of Ithaca, NY.

Component	microalgae
Crude protein (%)	17.3
Lignin (%)	2.3
Acid detergent fiber (%)	6.1
Neutral detergent fiber (%)	6.2
Water soluble carbohydrates (%)	1.8
Simple sugars (%)	1.0
Starch (%)	0.2
Non-fiber carbohydrates (%)	3.1
Crude fat (%)	1.4
Ash (%)	71.9
Calcium (%)	1.07
Phosphorus (%)	0.41
Magnesium (%)	0.78
Potassium (%)	0.80
Sodium (%)	1.34
Chloride (%)	2.09
Sulfur (%)	0.88
Iron (ppm)	23,900
Zinc (ppm)	254
Copper (ppm)	146
Manganese (ppm)	1,930
Molybdenum (ppm)	1.8
Cobalt (ppm)	11.17

Appendix 2

A concrete jersey wall barrier, shown below, was evaluated in order to illustrate how much dried algae could be used in a common construction item.. The volume of one 8 foot long jersey wall barrier was found to be 619824.31 cubic milliliters.



New Jersey Barrier Profile Dimensions