OPTIMIZE THE LIME CONTENT TO TREAT RECYCLED MUSHROOM SUBSTRATES IN CONCRETE

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ABSTRACT

Disposing spent mushroom substrate has been a major problem faced by farmers especially in areas such as Pennsylvania where its output far exceeds existing demand. And the high soluble salts concentration of these wastes has restricted their immediate application in the agricultural arena. Widespread and year-round field inventories of spent mushroom substrate created a great environmental nuisance because of various pollutants contained in the waste. In this research, we are trying to come up with a solution to recycle this farm waste as a part of concrete materials. They may be added as a sand substitute into those concrete used in constructing sidewalks, ground support for signboards or posts, sound walls, and other non-structural facilities. It was found that these wastes should be treated with quicklime or cement before being mixed into concrete as a partial substitute for sand. In order to make the recycling process both economical and applicable, the minimal amount of quicklime to be used in treating spent mushroom substrates and the maximal amount of sand that can be replaced was determined by considering both concrete strength and material costs. Based on some preliminary experimental results, a computational method is developed to evaluate the economical effect of recycling spent mushroom substrate into concrete.

KEYWORDS:

Spent mushroom substrates, Quicklime, Moisture content, Cost reduction, Sand

INTRODUCTION

Spent mushroom substrate (sometimes called mushroom soil, recycled mushroom compost, or mushroom compost) is the composted organic material remaining after a crop of mushrooms is harvested. Mushrooms are grown in a mixture of natural products, including horse-bedded straw (straw from horse stables), hay, poultry manure, ground corn cobs, cottonseed hulls, gypsum, and other substances. This mixture is composted in piles or ricks,

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creating a dark brown, fibrous, and pliable organic growing media. When the composting process is complete, the media is brought into mushroom houses where it is placed into beds or trays and used as a substrate for growing mushrooms. After the mushrooms are harvested, the "spent" substrate is removed from the houses and pasteurized with steam to kill insects, pathogens, and mushroom remnants. Spent mushroom substrate (SMS) is sometimes given away immediately after it is removed from mushroom houses; in this case it is referred to as "fresh SMS". Alternatively, the SMS can be placed in windrows and further composted for several weeks or several months. This material is often called "weathered SMS" and differs in composition and appearance from fresh SMS. (Landschoot and McNitt).

Traditionally, SMS was discarded as wastes, creating an environmental nuisance. The piles of SMS can create a negative runoff that includes aluminum and iron precipitates, as well as phosphorous and nitrogen, which are major sources of pollutants in lakes and streams. In recent years, mushroom growers all over the world are facing increasing pressure from environmental legislation, giving rise to the need for a more suitable solution for the disposal of SMS. Currently, SMS has been used in general agriculture as a soil remediation agent and in horticulture as mulch and as a component of soil mixes and potting soils. It is also used to fill abandoned strip mines, to inhibit the growth of some fungus (CAS 2000), to remedy contaminated water in wetlands (EPA 1997), and to apply as materials for various purposes of highway construction by State DOTs (EPA 2005). SMS should be treated to suit the specific demand of each outlet.

Despite those available outlets listed above, the enormous volume of SMS emanating from some production areas far exceeds their existing demand due to extremely higher output. For instance, mushroom production in the southeastern corner of Pennsylvania accounts for approximately 50% of the U.S. total crop. The constant overage in these areas has forced in to practice the widespread and year-round field storage of SMS. Even in those areas where the supply of SMS is offset by the local demand, considerable stockpiling occurs during certain time of the year because the demand tends to be seasonal (Romaine and Holcomb 2000). Furthermore, the implementation of SMS in the agricultural arena is restricted by its high concentration of soluble salts. Leachates and suspensions of fresh SMS contain up to 40-fold the concentration of inorganic salts that is known to be injurious to most plant species (Plaster, 1992; Szmidt and Chong 1995; Chorover et al 2000). Therefore, a field weathering process, where SMS is placed in windrows for passive leaching by rainfall and snowmelt, is normally required prior to its reuse (See Fig 1).

Fig 1: Field weathering of SMS

The primary goal of our research was to broaden the scope of application for SMS to stimulate its demand, and thereby reduce field inventories. Specifically, we are exploring the possibility of mixing SMS into concrete. The concrete containing SMS can be used in constructing sidewalks, ground support for signboards or posts, sound walls, and other nonstructural facilities. This approach will provide an alternative outlet for SMS. Unlike most other recycling methods, SMS don't have to be weathered in the field for months to be reused in the mixing of concrete. In other words, either "fresh SMS" or "weathered SMS" can be used in the in this recycling process. Thus this method is expected to reduce or eliminate SMS's harmful influence to the neighborhood environment (such as releasing offensive odors and changing the chemistry of underlying soil or even ground water). Some preliminary investigation of mixing SMS with fresh concrete had already been carried out (Kenyon, 2005).

MATERIALS AND METHODS

PROPERTIES OF SPENT MUSHROOM SUBSTRATE

Although many of the ingredients that go into SMS products are similar, not all products are alike. The composition of SMS can vary depending on the raw materials, how it is produced, and how it is treated after it comes out of the mushroom production houses. Therefore, The typical composition of spent mushroom substrate fresh from a mushroom house will vary slightly. And the "weathered SMS" has different characteristics because the microbial activity in the field will change the composition and texture and salt content may be changed during the aging period. A list of element and mineral analysis of SMS is shown in Table 1 (Beyer, 1999).

Table 1: the composition of SMS

AVERAGE ANALYSIS of SPENT MUSHROOM SUBSTRATE			
Contents	**Units**	**Avg. Fresh**	**Weathered 16 moth.**
Sodium, Na	% Dry Wt.	0.21 - 0.33	0.06
Potassium, K	% Dry Wt.	1.93 - 2.58	0.43
Magnesium, Mg	% Dry Wt.	0.45 - 0.82	0.88
Calcium, Ca	% Dry Wt.	3.63 - 5.15	6.27
Aluminum, Al	% Dry Wt.	0.17 -0.28	0.58
Iron, Fe	% Dry Wt.	0.18 - 0.34	0.58
Phosphorus, P	% Dry Wt.	0.45 - 0.69	0.84
Ammonia-N,NH4	% Dry Wt.	0.06 -0.24	0.00
Organic Nitrogen	% Dry Wt.	1.25 - 2.15	2.72
Total Nitrogen	% Dry Wt.	1.42 - 2.05	2.72
Solids	% Dry Wt.	33.07 - 40.26	53.47
Volatile Solids	% Dry Wt.	52.49 - 72.42	54.24
pH	Standard Units	5.8 - 7.7	7.1

Spent mushroom substrate products typically contain between 40 and 60% organic matter on a dry weight basis. The appearance of fresh SMS is similar to peat, with a light brown color and a light, fibrous texture. Weathered SMS products usually resemble dark topsoil and have a loose, crumbly structure. Fully composted SMS has an 'earthy' aroma and does not emit peculiar or offensive odors. However, anaerobic composting that cause objectionable odors seems unavoidable since there always exists some anaerobic areas in the composting process. The strength of that odor varies from one pile to another.

The moisture content of a SMS product is very important where uniform and good mixing is desired. Products with moisture contents between 30 and 50% are usually ideal for handling and uniform mixing with other materials. Wet SMS (greater than 60% moisture content) is heavy and tend to form big clumps. Thus wet products is difficult to handle and do not mix evenly with other materials.

THE ABSOLUTE VOLUME METHOD

One of the most often used methods of proportioning concrete is the absolute volume method, also known as the solid volume method and consolidated volume method. This method uses the specific gravities or densities for all the ingredients to calculate the absolute volume each will occupy in a unit volume of concrete. The absolute volume is

$$V_{\text{absolute}} = \frac{m}{(SG)\rho_{water}} \qquad V_{\text{absolute}} = \frac{W}{(SG)\gamma_{water}}$$

The absolute volume method assumes that, for granular materials such as cement and aggregates, there will be no voids between particles. Therefore, the amount of concrete is the sum of the solid volumes of cement, sand, coarse aggregate, and water. To use the absolute volume method, it is necessary to know the solid densities of the constituents. In the absence of other information, Table 2 can be used.

Table 2: Summary of Approximate Properties of Concrete Components

	Cement	Fine aggregate	Coarse aggregate	Water
specific weight	195lbf/ft^3	165lbf/ft^3	165lbf/ft^3	62.4lbf/ft^3
	3120kg/m^3	2640kg/m^3	2640kg/m^3	1000kg/m^3
specific gravity	3.13	2.64	2.64	1.00

EXPERIMENT AND METHOD

The method adopted in our study was to replace a certain amount of sand with SMS in the proportioning of concrete by volume. According to the above-mentioned absolute method, the solid volume of SMS should be equal to that of sand being replaced. Considering SMS without agglomerating have similar particle sizes as sand, we assume the amounts of SMS and sand with same apparent volumes should have similar solid yield as ingredients of concrete. The fact shown in our experiment that no apparent change of total solid yield of concrete was found after replacement of sand with SMS justified our assumption.

A control batch with no SMS was first made to set a basis for proportioning design of other batches. This batch was also tested to compare with those batches containing SMS. The coarse aggregates used were crushed granites with maximal nominal size of 3/4 inch purchased from a local supplier. The fine aggregate was Quickete sand and the cement was Type I. The proportioning of ingredients can be seen in Table 3.

Table 3: Design proportioning of control batch

Ingredients	Weight (lb)
Coarse Aggregate	75.6
Fine Aggregate	57.7
Cement	27.7
Water	13.8

It was observed in some previous experiments that concrete mixed with fresh SMS not only failed to set two weeks after mixing but also released strong offensive odors. Treating SMS with quicklime can improve this situation. It was found in our experiments that concrete could harden in about one week if SMS is treated with a certain amount of quicklime prior to mixing. The SMS used in our study came from a Chester County mushroom farm with moisture content about 60%. Its dry density is about 1/7 of sand. It is believed that quicklime can stabilize the pH of SMS and reduce peculiar odors by halting anaerobic digestion and getting rid of the ammonia present in fresh SMS.

Four different batches of concrete mixed with SMS were produced and tested. Proportioning of ingredients (by volume) was kept the same as that of control batch. Moisture content in SMS was taken into consideration; i.e. the actual water added into the mixture is less than that of control batch. A significant difference is that in these batches fine aggregate comprises of both sand and SMS. In the first two batches, 20% of total sand was replaced by the same volume of SMS whose dry solid content weighs about 1/7 of those sand being replaced. For the first batch (SMS-1), the weight of quicklime used for treating SMS equaled to moisture content of SMS; while for the second batch (SMS-2), the weight of quicklime used for treating SMS was 1/3 of the moisture content in SMS. In the following two batches, the total sand replaced by SMS was increased to 30%. For the third batch, the weight of quicklime consumed was also 1/3 of the moisture content in SMS. For the last batch, it is decided to treat SMS with cement, and the amount of cement consumed in treating SMS was equal to moisture content of SMS.

RESULTS AND DISCUSSION

ANALYSIS OF TEST RESULTS

Fifteen 4’’ x 8’’ cylinder specimens were produced out of the control batch. They were cured for 28 days and then tested using the Forney Compression Tester. The highest and lowest compressive strength were 36.13 MPa (5235 psi) and 31.94 MPa (4629 psi) respectively. Average strength was found to be 33.77 MPa (4893 psi), which is above the required strength for general construction purpose (Somayaji, 2001). The standard deviation of the strength, observed to be 0.99 MPa, was approximately 2.9% of the average strength.

In the first two SMS batches, where concrete strength of 7 days, 14 days, and 28 days were tested, it is found that uncured specimens showed consistently higher strength than cured specimens (See Table 4). As also shown in the table, concrete containing SMS had either higher or comparable compressive strength compared with normal concrete represented by control batch. A possible explanation for this phenomenon is that SMS could affect concrete strength in two ways. On the one hand, SMS can benefit concrete strength in that it will absorb some water that is believed to be responsible for leaving pores in cement matrix (much like the effect of decreasing water cement ratio); On the other hand, it can damage concrete strength since the presence of small SMS clumps and other small pieces of solid will disrupt the cement matrix.

Table 4: Comparison of compressive strength (psi)

Days	Control batch	SMS-1		SMS-2	
		Cured	Uncured	Cured	Uncured
7	3425	3645	3909	2956	2866
14	4601	4553	4902	4168	4196
28	4893	5058	5476	4418	4936

It is indicated in the following two batches that the 28-day compressive strength of concrete is still comparable with control batch when the amount of sand replaced by SMS is increased to 30%. However, as we can see from Table 5, concrete strength decreased about 9% from SMS-2 to SMS-3 where the same treatment method is adopted. This might be an indication that the beneficial effect of SMS mentioned above began to be overwhelmed by its detrimental effect on concrete strength. The higher coefficient of variation of SMS batches compared with control batch was primarily due to uneven distribution of small SMS clumps.

SMS Percentage	0	20%		30%	
Batch Name	Control batch	SMS-1	SMS-2	SMS-3	SMS-4
Treating Method*	N/A	Quicklime	Quicklime	Quicklime	Cement
		1:1	1:3	1:3	1:1
Average Strength (psi)	4893	5476	4936	4501	5055
Strength (MPa)	33.77	37.76	34.03	31	34.86
Standard Deviation (MPa)	0.99	NA	NA	3.92	1.9
Coefficient of Variation	2.9%	NA	NA	12.6%	5.5%

Table 5: Comparison of concrete strength with different amount of SMS

*The ratios listed in this column represent the weight of treatment materials to moisture weight in SMS.

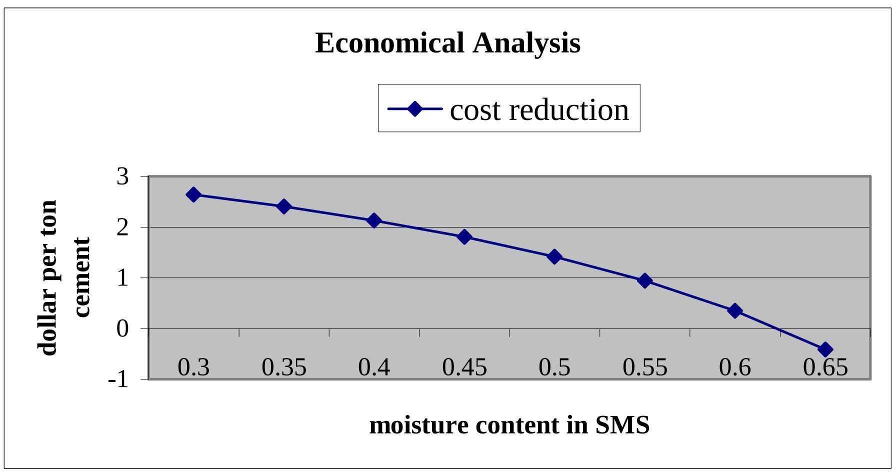
ECONOMICAL EVALUATION

Since the cost of buying SMS are either zero or negligible compared to the other ingredients of concrete (depends on the owner), the material cost of producing concrete can be cut down by replacing a certain amount of sand with SMS. Assume a mix is designed just like our control batch where the proportioning of cement, fine aggregate, coarse aggregate, and water is 1:2.08:2.73:0.5 by weight. According to the U.S. Geological Survey, for the year 2005 the average price of sand and gravel was about \$5.70 per ton; quicklime's average value was about \$72 per ton. Let ω represent moisture content percentage of SMS and λ represent the ratio of the weight of treating material to moisture content in SMS. When α% of sand is replaced with SMS, total material cost reduction for concrete generating from per ton of cement should be expressed as the following formula (the save created by reduced cost of sand minus the cost of lime needed to treat SMS):

$$R = 2.08 \times 5.7 \times \alpha\% - \left(\frac{2.08 * \alpha\%}{7} \times \frac{\omega}{1-\omega} \times \lambda\right) \times 72$$

If we adopting λ = 1/3 and α% = 30%,

$$R = 30\% \times \left[2.08 \times 5.7 - \left(\frac{2.08}{7} \times \frac{\omega}{1-\omega} \times \frac{1}{3}\right) \times 72\right] \approx 5.696 - 2.139\frac{1}{1-\omega}$$



Obviously, R is a descending function of ω and remains to be positive until ω increases to 62.5%. The less water SMS contains the more cost reduction will be achieved. Therefore, it's advisable to use SMS with low moisture content in the recycling into concrete mix because those with higher water content are not only hard to handle but also costly.

CONCLUSIONS

It is found in our study that Spent Mushroom Substrate can be economically recycled as a component of concrete. The costs associated with treating the SMS are optimized in this study to meet various technical requirements. The concrete containing SMS is expected to be used in the construction of sidewalks, ground support for signboards or posts, sound walls, and other nonstructural features for buildings. At least up to 30% of fine aggregate can be substituted by SMS without significantly reduce the concrete strength. The SMS should be treated with either quicklime or cement before mixing into concrete to facilitate concrete hardening and reduce the offensive odors. The desired amount of quicklime being used is recommended as about 1/3 of the moisture content by weight. This amount will result in a material cost reduction and an acceptable concrete strength. Conducting durability analysis for concrete containing SMS and figuring out a more cost effective way to make it more attractive to possible users would be two very important issues to be addressed in the near future.

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