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Mixing Reservoir Sediment with Fly Ash to Make Bricks and Other Products

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ABSTRACT

Taiwan (the Republic of China) relies heavily on reservoirs for water supply, flood control, irrigation, hydropower, and recreation. The sedimentation of such reservoirs over the years has caused large capacity losses of the reservoirs, threatening the wellbeing of the island nation. Dredging (including excavation of exposed reservoir bank and bottom during low flows) has been used to remove the deposited sediments. How to best dispose of or utilize the dredged sediment remains an important challenge to Taiwan and many other nations. The purpose of this paper is to describe an ongoing research project seeking to utilize the dredged reservoir sediments for making bricks and other construction or gardening products (blocks). Fly ash is used as a cementing agent to facilitate the making of such bricks and blocks.

The project is exploring two alternative methods to make bricks from reservoir sediment: a high-temperature and a room-temperature process. The high-temperature process is similar to the use of clay to make fired-bricks in conventional brick manufacturing; a temperature of the order of 1000 ^{o}C is required for the clay to vitrify. This process does not require the use of fly ash, though adding fly ash to the sediment may be desirable in situations such as when there is a need to find a beneficial use of the fly ash, or when it is difficult to form and maintain good brick shapes without fly ash prior to firing/vitrification.

The room-temperature process for making sediment bricks uses fly ash. In this process, reservoir sediment is mixed with fly ash and a small amount of water. The mixture is then compacted in a mold (die) to form an agglomerate of brick shape or other desired shapes -- depending on the mold shape. Because the fly ash in the mixture contains cementitious materials such as CaO, upon setting and curing, hard and strong bricks, similar to concrete bricks, can be produced. The preliminary study shows that for bricks of good strength, either type C fly ash must be used, or some CaO must be added to the type F fly ash. Even though this study is still ongoing and inconclusive, it does show that strong bricks can be made at room temperature by using fine sediment mixed with fly ash, with or without the addition of lime (CaO), depending on the CaO content in the fly ash used.

So far, both the high-temperature and the room-temperature processes for making bricks from reservoir sediments have not yet been optimized. With optimization, stronger and better-quality products can be produced. Planned future research in this project involves the following for the high-temperature process: finding the optimal temperature for producing the sediment bricks, finding the optimum forming pressure for forming the bricks prior to heating them, adding fly ash and/or CaO to the sediment in order to help forming and maintaining better brick shapes prior to the heating process, etc. For the room-temperature process, the planned research includes determining the optimum amount of CaO needed in any fly ash to produce strong bricks, the optimum water contents and compaction pressures needed under various conditions to produce best bricks, etc. This paper will focus on the room-temperature process.

INTRODUCTION

Taiwan, the main territory of the Republic of China, is an island of 13,885 sq mi (35,961 sq km) that has a population of about 18 million. In contrast, the Netherlands has an area of 15,963 sq mi (41,344 sq mi) and a population of 13 million; the State of Kentucky has an area of 40,395 sq mi (104,623 sq km) and a population of 4 million. Therefore, Taiwan is slightly smaller than the Netherlands but has a slightly higher population than the Netherlands. It is about one-third of the area of Kentucky, having more than four times the population of Kentucky.

Being an island with high mountains in the central region, Taiwan’s rivers and creeks are typically short and steep. Without reservoirs, not much water can be retained in the rivers or underground aquifers to sustain the large population of Taiwan and its economic development. Consequently, in the last 100 years, approximately 70 dams were constructed on various rivers in Taiwan to retain water in reservoirs. Most of these reservoirs are for multipurpose: water supply, irrigation, hydropower, flood control, and recreation. They are vitally important to the wellbeing of Taiwan.

Unfortunately, most of these reservoirs are quickly losing their capacity for holding water due to sedimentation. According to recent statistics, sedimentation is causing Taiwan’s reservoirs to lose more than 15 million cubic meters (530 million cubic feet) of capacity each year. On the average, Taiwan’s reservoirs have lost about 20% of their effective capacity due to sedimentation; six of these reservoirs have already lost more than 50% of their capacity. Large losses of capacity often follow typhoons, which bring large precipitation to the island in a short period, often within hours. The resultant flash floods cause serious soil erosion in highlands, which in turn brings large amount of sediments into reservoirs. Poor conservation practices in the past, including deforestation by the timber industry, careless mining and excavation practices, and cultivation of steep lands for agriculture purposes, all exasperated the erosion/sedimentation problem. Even though such abuses in land use have gradually been brought under control in recent years, erosion due to natural causes such as typhoons will continue to plague Taiwan’s reservoirs, and dredging of reservoir sediment will continue to be needed in the future to maintain the reservoirs’ capacity. In addition to dredging, some reservoirs in Taiwan also seek to reduce their deposited fine sediments by flushing them out at times of high pool level. Still, dredging remains to be the most effective and widely used practice in Taiwan to combat reservoir sedimentation problem, and to maintain reservoir capacity for long-term use.

Unlike sediments deposited on river banks which are mostly sand, the sediments deposited in reservoirs are mostly clay containing a few percent of organics. The fine particle size of the reservoir sediments renders the sediments unsuitable for use as concrete mix in ordinary construction. It is also difficult to dispose of such material without causing environmental problems. Consequently, finding any beneficial use of the dredged reservoir sediments is highly important to Taiwan. In recognition of this fact, the Water Resources Agency, under the Ministry of Economic Affairs, is currently paying great attention to finding satisfactory solutions to the problem, such as supporting this 4-year study which is currently in its second year. Legislations are also being drafted by the government to improve the management of the reservoir sedimentation problem in general, and to promote beneficial uses of the dredged sediments in particular.

The purpose of this project, sponsored by the Water Resources Agency, is to test two promising processes, a room-temperature process and a high-temperature process, that use reservoir sediments to make construction or gardening block-type products such as bricks. Since Taiwan's economic development is at a fast paste, there is a large and long-term market for such block-type construction materials, to be used for buildings, fencing, windbreaks, breakwaters, dikes, road pavement, retaining walls, lining of river banks, gardening, and many other possible usages. This paper is focused on the low-temperature process which requires the use of a substantial amount of fly ash as the cementing agent, and a high compaction pressure in order to produce strong bricks and blocks.

Because Taiwan's electric power is heavily reliant on imported coals, how to utilize the large amount of fly ash generated each year in Taiwan by the Taiwan Power Company and other industries also represents a major challenge to Taiwan. Therefore, it makes a great deal of sense to use the fly ash generated in Taiwan as the binder (cementing agent) of the dredged reservoir sediments to make good bricks. It should be realized that to a certain extent, fly ash contains the same basic ingredients of and behaves like the ordinary Portland cement. It contains both pozzolanic materials (i.e., glass-making materials such as SiO_2, Al_2O_3 and Fe_2O_3) and cementitious materials (i.e., materials that, upon contact with water, cause cementation actions, as for instance CaO). While ordinary cement contains over 60% of CaO, the CaO content of fly ash is usually much less – over 10% for Type-C fly ash, and less than 5 % for Type-F fly ash. For the room-temperature brick-making process, it is the cementitious reaction of the CaO in the fly ash, that causes binding of the pozzolanic materials in both the fly ash and the sediments). Upon setting and curing, concrete-like bricks are produced. The chemical reaction involves the following two steps:

Step 1: Hydration of Quick Lime:

$$\underset{\text{Quick lime}}{CaO} + H_2O \rightarrow \underset{\text{Hydrated lime}}{Ca(OH)_2} + Heat \qquad (1)$$

Step 2: Reaction of hydrated lime with pozzolanic materials:

$$Ca(OH)_2 + SiO_2 + H_2O \rightarrow CaO \cdot SiO_2 \cdot H_2O \qquad (2)$$

and

$$Ca(OH)_2 + Al_2O_3 + H_2O \rightarrow CaO \cdot Al_2O_3 \cdot H_2O \qquad (3)$$

LITERATURE ON FLY ASH COMPACTION

In 1996, Parsa et al., at the New Mexico State University, conducted a laboratory study that involves using fly ash to stabilize and solidify hazardous radioactive waste materials [1]. They mixed the hazardous waste material with fly ash, and compacted the mixture into monoliths (solid cylindrical objects). The monoliths were then tested for their compressive strength, and were broken up for the TCLP (Toxicity Characteristic Leaching Procedure) test, which is a standard test procedure embraced by the U.S. Environmental Protection Agency. Their tests indicated that the type of fly ash used, the pH value of the waste, and the compaction pressure are important factors affecting the compact strength, and the TCLP test results. For instance, it was found that the optimum compaction condition for Class C fly ash was at compaction pressure of 675 psi (4.65 MPa) and pH of 9.2. The highest compaction pressure they used in making the monoliths was 3,000 psi (20.7 MPa).

In 1995, Kube and Palit in India compacted a mixture of fly ash, pond ash, lime and sand to make bricks [2]. By using compaction pressure of 240 Kg/cm^2 (3,411 psi) and upon 6 hours of steam curing, the bricks were found to have a compressive strength of 140 Kg/cm^2 (1,989 psi), The bricks were judged to be unsatisfactory due to their high water absorption (13-22 %), high porosity and low abrasion resistance.

Wolfe et al., at Ohio State University, explored the suitability of using a mixture of Class C fly ash and flue gas desulfurization (FGD) materials to produce a low permeability liner [3]. They mixed the fly ash with the FGD materials (namely, the filter cake) and lime, and compacted the mixture sample by dropping 5.5 lb hammer from a height of 1 ft (305 mm), as prescribed by ASTM D698. The study revealed that the compacted product, having a permeability coefficient in the neighborhood of 10^{-7} cm/s or 10^{-9} m/s, can be used as a low permeability filter.

The most important known previous study on compaction of fly ash is research conducted at the University of Missouri-Columbia. In 2001, Hu completed an M.S. thesis entitled “High-Pressure Compaction of Flyash into Building Materials”[4]. In this study, Hu used both a high-grade fly ash and a low-grade fly ash obtained from the Thomas

Hill Power Plant in Missouri to made cylindrical compacts or test samples, called “flyash logs.” Both the high-grade and the low-grade fly ash were derived from burning subbituminous coals mined in Wyoming. The main difference between these two types of fly ash is the amount of the unburned carbon in the fly ash — i.e., loss on ignition (LOI). While the high-grade type, collected from pulverized-boiler units, had an LOI of less than 1%, the low-grade type, collected from cyclone-boiler units, had an LOI higher than 9%. The logs were produced by compacting fly ash mixed with a small amount of water, using a cylindrical mold and a cylindrical piston (rod), both of which made of stainless steel. Upon ejection from the mold, the “logs” had a uniform diameter of 48.7 mm, a length in the range 68 ~78 mm, and a weight between 245 and 281 gm. Figure 1 shows a set of such logs compacted at the same pressure but different flyash-to-water ratios (F/W ratios). The ejected logs were then cured over various periods, and then tested for compressive strength and other properties. Various factors that affect the strength of the compacted products were tested, including the F/W ratio, compaction pressure, curing time, and curing methods. The tests revealed the following:

- Generally, the high-grade (low-LOI) fly ash produces much stronger compacts (logs) than the low-grade (high-LOI) fly ash.

- Usually, higher compaction pressures produce stronger logs. However, for the low-grade fly ash, compaction pressures higher than 5,000 psi result in cracks on logs and a decrease in strength.

- At compaction pressure of 5,000 psi, the optimum F/W ratio is 9.0 (i.e., 90 % fly ash and 10 % water) for the high-grade fly ash, and it is 5.67 (i.e., 85% fly ash and 15% water) for the low-grade fly ash. Generally, increase in water content increases the strength and density of the logs until the foregoing limits were reached. Increase in the water content of the mixture also reduces the amount of water absorbed later during curing. More water means more hydration of lime. However, too much water in the mixture causes both a dilution of the hydrated lime and rapid setting, both of which are undesirable.

- Curing increases the strength of fly ash logs. An effective way to cure is simply placing the newly compacted logs in a moist-air environment for at least 24 hours. Then the logs can be immersed in water without damage, and with continued increase in strength over a long time.

- The density of the logs increases with increasing compaction pressure, and with increased curing time.

- Generally, the permeability (hydraulic conductivity) of the logs decreases with compaction pressure. For the high-grade fly ash logs, the permeability decreases to about 10^{-8} cm/s (10^{-10} m/s) at 16,000 psi compaction pressure, and for the low-grade fly ash the permeability decreases to about 10^{-8} cm,/s (10^{-10} m/s) when the compaction pressure is around 6,000 psi.

- The compressive strength of the logs made of the high-grade fly ash having F/W ratio of 9 and compacted at 5,000 psi is approximately 34 MPa (4,900 psi) after 7 days of curing, and the strength increases with curing to 55 MPa (8,000 psi) and 76 MPa (11,000 psi) after respectively 28 days and 60 days of curing in water. Such strength matches that of high-strength concrete.

Based on the above test results, Li and Lin, in 2002 [5], used the same two types of fly ash tested by Hu, and the same procedure to compact full-size fly ash bricks of 8-inch (203-mm) length, 4-inch (102-mm) width and 2.2-inch (56-mm) thickness – see Figure 2. The flyash-to-water ratio used was 9 (i.e., 10% water based on the wet weight of logs) for the high-grade fly ash, and 5.67 (15% water based on the wet weight of logs) for the low-grade fly ash. Most of the bricks were compacted at 1,800 psi. Some bricks were compacted at different pressures ranging from 600 psi to 10,000 psi, to investigate the effect of compaction pressure on brick quality. Upon curing, each brick was tested of compressive strength, modulus of rupture, water absorption and freezing-thawing resistance. Note that ASTM standards require that half-bricks be used in some of these tests. The test results for bricks compacted at 1,800 psi are summarized in Table 1. Also included for comparison in Table 1 are the corresponding properties of a typical commercial brick, and the corresponding ASTM requirements on various types of bricks. Table 1 reveals the following facts:

- Even at the relatively low compaction pressure of 1,800 psi, upon 7 days of curing, both the high-grade-fly-ash and the low-grade-fly-ash bricks have compressive strengths higher than those called for by ASTM standards for clay and shale bricks (3,000 psi), and for Grades S-1 and S-2 of concrete bricks.

- Upon 28 days of curing, the high-grade-fly-ash bricks compacted at 1,800 psi gains a compressive strength exceeding that of a typical fired clay brick.

- The modulus of rupture (i.e., the flexural tensile stress that causes the brick to fail) of the fly ash bricks is much lower than that of ordinary fired clay bricks. However, for most applications, such as building bricks, this property is unimportant and hence not required by ASTM standards.

- The fly ash bricks tested for freezing-thawing failed after 7 to 9 cycles, whereas ASTM Standard C67 requires 50 cycles. This appears to be the biggest weakness of the fly ash bricks. However, this result should be kept in proper perspectives. First of all, in geographical regions that have warm climates, bricks will never freeze in winter time, and hence the freezing-thawing will never occur to or damage the fly ash bricks. Secondly, the fly ash bricks that were tested for freezing-thawing were compacted at 1,800 psi and cured for 28 days. Increasing the compaction pressure and lengthening the curing time will both result in stronger bricks that can withstand more cycles of freezing-thawing. There are also other ways to improve the freezing-thawing resistance of the compacted fly ash bricks. It is important that future research will address this issue, and will find ways to enhance the freezing-thawing resistance of fly ash bricks. Thirdly, it should be realized that few commercial brick suppliers test their bricks for ASTM requirements or claim that their bricks meet all ASTM Standards.

- The water absorption of the high-grade fly ash bricks is about 10%, which meets both ASTM Standard C55 for concrete building bricks, and ASTM Standard C62 for clay and shale bricks. The water absorption of the low-grade fly ash bricks is about 21 %, which exceeds both ASTM Standard C55 and C62. Again, increasing the compaction pressure to beyond 1,800 psi and increasing the curing time to beyond 28 days will reduce the water absorption of the fly ash bricks. They should be tested in order to make the product of the low-grade fly ash to meet the ASTM standards.

Note that the Missouri study also included paving a section of a walkway on campus for long-term observation of the performance of the compacted fly ash bricks – see Figure 3.

EXPERIMENTS

The current project in Taiwan involves a variety of tests including the following:

1. Test of Sediments Properties

The sediment used for making bricks in this project was obtained from the sedimentation basin of the Shimen Reservoir in northern Taiwan. Upon drying, the sediment was passed through a sieve of 2 mm mesh size. Only those particles that had passed through the sieve were used in the experiment. The chemical composition of the sediment is 61% SiO_2, 17% Al_2O_3 and 7% Fe_2O_3. The rest of the components include other inorganics, organics, and heavy metals. The sediment was also tested for various physical properties including original water content, specific gravity, porosity, liquid limit, plastic limit, and plasticity index.

2. Test of Fly Ash Properties

The fly ash used in the tests came from two different power plants in Taiwan: (A) the Taiwan Power Company's Lin-Cow Power plant, and (B) the Taiwan Plastic Company's Mai-Liao Power Plant. The former has a CaO content of 2.73 and the latter has a fly ash content of 2.48, both approximately. Both are Class F fly ash.

3. Compaction of Fly Ash to Make Logs and Bricks

So far, only preliminary compaction tests have been conducted for this project. The first set of tests involve compacting the fly ash from the two plants without sediment. It was done at the compaction pressure of 3,000 psi and three flyash-to-water (F/W) ratios: 5.0, 3.33, 2.5, which are equivalent to 20%, 30% and 40% water, respectively. After 14 days of curing, the logs were tested for their compressive strengths and water absorption. It was found that the products strength was very weak, and the compacts dissolved in water upon immersion. The prime reason for the poor result must be caused by insufficient concentration of lime (CaO) in the Taiwan fly ash used in the test – less than 3%. Since CaO is the prime cementing material in fly ash, having only 3% Cao in the Taiwan fly ash is insufficient to make good bricks. The problem may also be caused by too much water in the mixture used in the preliminary tests. While the highest F/W ratio of this test was 5.0, the optimum F/W ratio found in the Missouri tests was 5.67 for the low-grade fly ash, and 9.0 for the high-grade fly ash. This shows that the preliminary test conducted in Taiwan might have used too low F/W ratios, or too much water in the mixtures. Since water chemically react primarily with the CaO in any fly ash, for fly ash of low concentration of CaO, less water is needed for chemical reaction.

A second set of preliminary tests was held, in which fly ash with various water contents ranging from 10% to 40% (corresponding to F/W ratios of 10 to 2.5) was compacted at three pressures: 5,000, 10,000 and 15,000 psi. It was found that the the strongest compact was produced at the F/W ratio of 10 and compression pressure of 15,000 psi. This again showed that too much water can be harmful.

4. Compaction of Mixtures of Fly Ash and Sediment

Sediment-flyash mixture of 3 to 1 (i.e., 3 parts of sediment mixed with 1 part of flyash) was mixed with 10 % water (based on the weight of total solids in the mixture) and then compacted at 15,000 psi. Then the product was cured in a plastic bag containing moist air for different periods before tested for the compressive strength. The test result is shown in Figures 4 and 5. It can be seen from the two figures that the logs gained more than 90% of the final strength in two days of curing. After 2 days, the logs made from mixing sediment with fly ash A (which is from the Lin-Cow Power Plant) had a compressive strength of 500 psi approximately, and the logs made from mixing sediment with fly ash B (which is from the Mai-Liao Power Plant) had a compressive strength of 600 psi approximately. Both sets of logs did not pass the water absorption test; they melted in water upon immersion.

5. Compaction of Mixtures of Fly Ash, Sediment and Lime (CaO)

To improve the quality of the compacted products, lime (CaO) was added to the sediment-flyash mixture. The lime-flyash ratio was 1 to 1; the sediment to flyash ratio was 3 to 1; the water content was 10% (based on the total weight of the combined solids in the mixture), and the compaction pressure was 15,000 psi. The products were then cured in moist air. Figures 6 and 7 show the gain of strength with time for the compacts made from the mixtures that contained the fly ash from the two power plants, A and B, respectively. As can be seen from these two figures, these logs are much stronger than those made without lime. From Figure 6, the products containing fly ash A had a 3-day strength of 1,600 psi approximately, whereas from Figure 7 the products containing fly ash B had a 3-day strength of 2,100 psi approximately. In both cases, the logs produced did not melt or dissolve in water upon immersion. However, it can be seen from these two figures, especially Figure 7, that wet-curing in water (i.e. immersion in water) is detrimental to the long-term strength of the logs. A summary of the test results is given in Table 2.

CONCLUSION AND FUTURE RESEARCH

Based on the aforementioned preliminary test results of this project, the following temporarily conclusions can be reached:

- Reservoir sediments can be made into bricks by using the room-temperature compaction process if fly ash (or fly ash and lime) are added to the sediment before compaction.
- Compacting sediment at room-temperature with fly ash but without the addition of lime (CaO) resulted in relatively weak bricks of compressive strengths in the neighborhood of 500 to 600 psi, and the product failed the water absorption tests. Adding lime to the sediment-flyash mixture at a flyash-to-lime ratio of 1 to 1 resulted in a substantial increase in the strength of the compacts (to 1600 to 2100 psi). Besides, the resultant compacts passed the water absorption test.
- Much more research is needed to determine the optimum conditions of the room-temperature compaction process for making good-quality bricks, including the maximum sediment-to-flyash ratio, the optimum water content, the minimum CaO concentration needed in the mixture, the optimum compaction pressure, etc.

Based on the preliminary test results and the temporary conclusions reached, the future research of this project for the remaining two-and-half years will be focused on optimizing both the room-temperature and the high-temperature processes. It is felt that once the processes are optimized, they will be able to produce bricks and products of other shapes with much stronger strength and lower water absorption than have been achieved so far. After the processes have been optimized based on compressive strength and water absorption, other key properties of the optimized products will also be tested and assessed, including the rupture modulus (i.e., the flexural strength which is the tensile strength measured from bending), freezing-and-thawing resistance, impact resistance (drop test), wear resistance (tumbler test), and pollutant-leaching resistance (TCLP test). The remaining research will also include an evaluation of the equipment and facilities needed for mass production of both the room-temperature and the high-temperature bricks, and the respective unit production costs in $ per 1000 bricks produced. The unit production costs will be determined from a life-cycle cost analysis of a typical plant for producing such bricks, in a manner as determined in Reference 5.

ACKNOWLEDGMENT

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Table 1 Properties of fly ash bricks compacted at 1,800 psi and cured for different periods as compared to properties of a regular commercial brick and ASTM standards.

Brick Type	Curing Time (days)	Compressive Strength (psi)	Modulus Of Rupture (psi)	5-hour Water Absorption (%)	24-hour Water Absorption (%)	Freezing-Thawing (cycles)
High-grade fly ash	7	4,680	342	12.6	12.8	--
“	28	7,850	350	10.6	10.7	7-9
“	60	8,641	354	9.8	10.0	--
“	90	9,330	441	10.9	11.2	--
Low-grade Fly ash	28	3,210	203	20.4	21.1	7-9
Regular fired clay brick	N/A	6,510	2030	0.30	0.55	>9
Concrete building bricks (ASTM Standard C55)	N/A	>3,000 for individual units under most severe conditions (Grades N-1 & N-2)	--	--	< 14 (15 lb of water in 105 lb of lightweight concrete)	--
Building bricks made of clay or shale (ASTM Standard C62)	N/A	>2,500 for individual units under most severe conditions (Grade SW)	--	<20 from 5 hours of boiling	--	--
Bricks (ASTM Standard C67)	N/A	--	--	--	--	> 50

Table 2 Comparison of the strengths of compacts made of sediment and fly ash with or without lime (CaO) (Note: Values listed are compressive strength in psi.)

Mixture Composition	Curing or Not?	Curing Period						
		0 day	1 day	2 day	3 day	7 day	14 day	28 day
F_A + S	No	0	420	485	504	517	543	550
F_B + S	No	0	592	600	589	614	562	608
F_A + S + L	No	0	1078	1355	1627	1878	2522	1532
“	Yes	0	1078	1355	1627	1810	2070	1500
F_B + S + L	No	0	678	1360	2033	1966	2182	2106
“	Yes	0	678	1360	2033	1623	1177	689

Note: F_A = fly ash from Power Plant A; F_B = fly ash from Power Plant B;
S = Sediment; L = Lime (CaO)

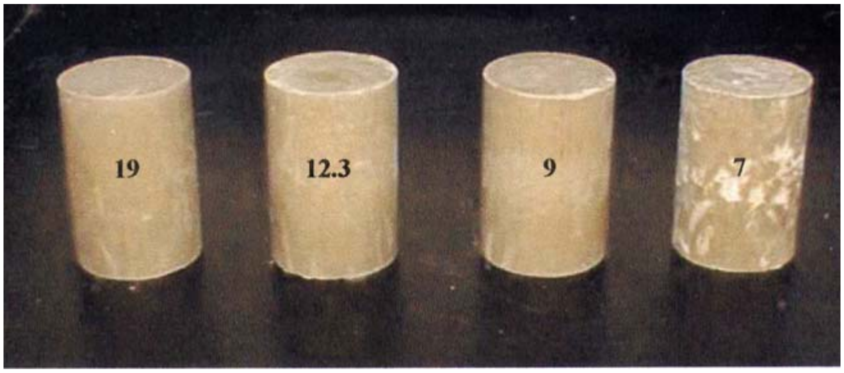

Figure 1 High-grad fly ash logs compacted at 5,000 psi and different F/W ratios (Note: The number marked on each log shows the F/W ratio.)

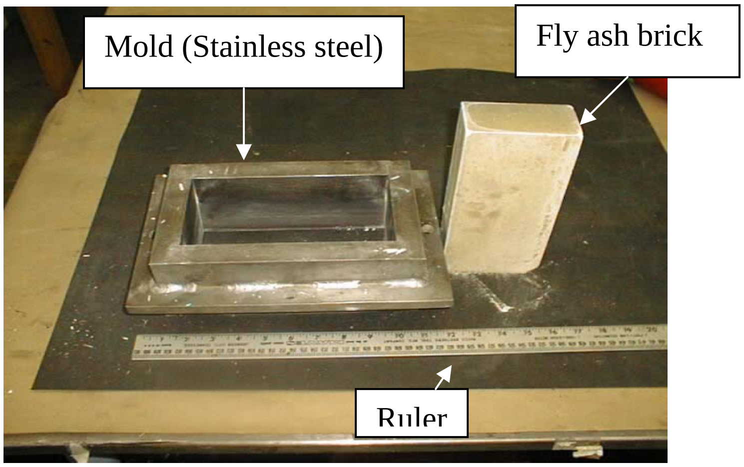

Figure 2 Compacted fly ash brick and the mold (die)

Figure 3 Compacted fly ash bricks tested for use as walkway pavement on the campus of University of Missouri-Columbia.

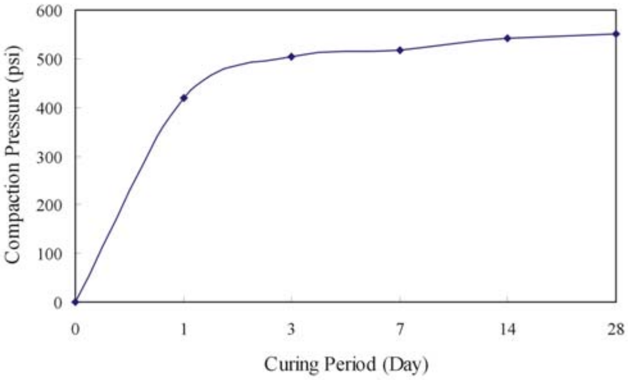

Figure 4 Compressive strength of logs made of sediment and fly ash A (S/F = 3.0; compaction pressure = 15,000 psi; water content = 10%)

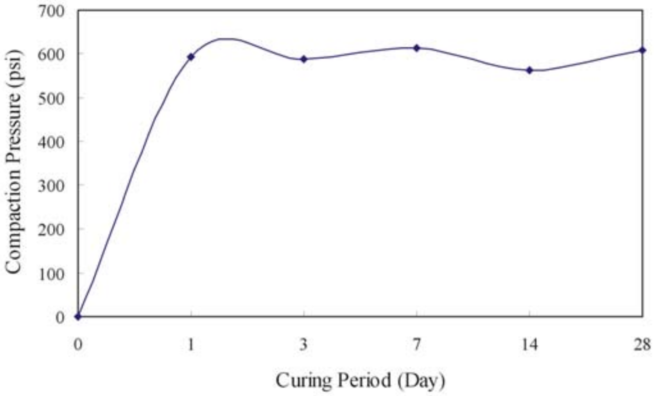

Figure 5 Compressive strength of logs made of sediment and fly ash B (S/F = 3.0; compaction pressure = 15,000 psi; and water content = 10%)

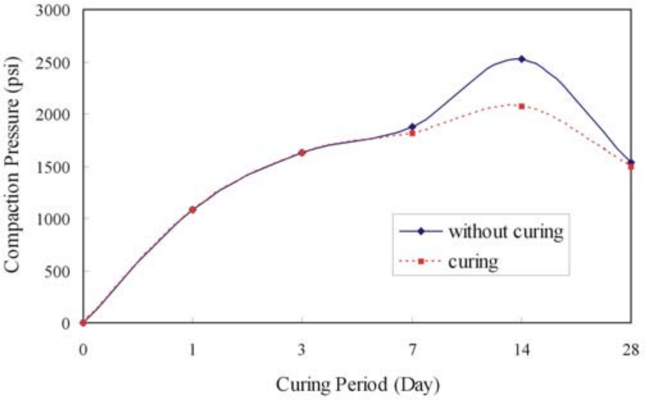

Figure 6 Compressive strength of logs made of adding lime to sediment and fly ash A (S/F = 3.0; L/F = 1.0; compaction pressure = 15,000 psi; water content = 10%)

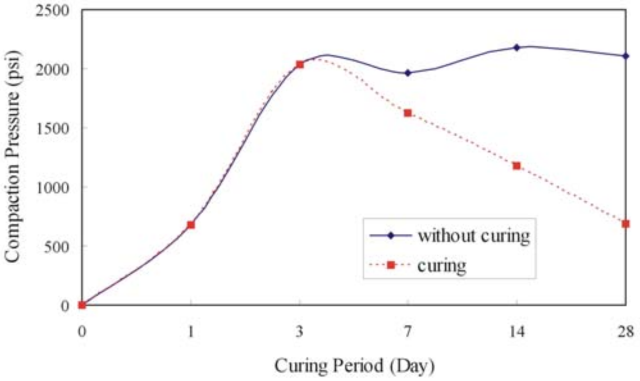

Figure 7 Compressive strength of logs made of adding lime to sediment and fly ash B (S/F = 3.0; L/F = 1.0; compaction pressure = 15,000 psi; water content = 10%)