

# Effect of Cenospheres on Flyash Brick Properties

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## Introduction

In January 2006, the National Science Foundation awarded Freight Pipeline Company (FPC) with a Small Business Innovation Research (SBIR) Phase II grant. This grant enabled FPC to continue testing the durable 100% flyash brick developed during Phase I, in an effort to achieve commercialization by 2008. Under this research, cenospheres were evaluated to determine their usefulness as an additive to flyash to improve the brick's properties.

Cenospheres are a powdered material derived from the flyash of coal-fired power plants. A cenosphere is a small sphere that is hollow, light-weight and filled with an inert gas. The color of the sphere varies from an almost white to grey. The specific gravity of the sphere ranges from 0.4 to 0.8. Burning coal produces flyash containing small ceramic cenospheres, which are particles made largely of alumina and silica. These cenospheres are produced at high temperatures of 1500-1750°C through complicated chemical and physical transformations during the combustion of coal. The amount of silica and alumina in the cenosphere depends greatly on the coal that generated them[1].

As part of the Phase II research, the possibility of replacing a portion of the flyash with cenospheres to improve certain properties of the brick was studied. It was expected that the bricks made of flyash that contained cenospheres may lower the density and enhance the freeze-thaw resistance. Bricks containing 0 to 20% cenospheres by weight were produced and tested for compressive strength and freeze/thaw durability according to the ASTM standard for fired clay bricks.

The standard used for freeze-thaw testing of flyash bricks was the ASTM standard C67 entitled "Test Method for Sampling and Testing Brick and Structural Clay Tile"[2]. This standard was used since there is currently no standard for testing flyash bricks. ASTM standard C 67 outlines ways of testing modulus of rupture, compressive strength, absorption, saturation coefficient, effects of freezing and thawing, efflorescence, initial

rate of absorption and determination of weight, size, warpage, length change, and void area for clay bricks and tiles used for buildings.

### **Brick Manufacturing Method**

For manufacturing the flyash bricks used in this research, an electronic scale is used to weigh the appropriate amount of flyash. Using the electronic scale, the specified amount of wet mixture of air entrainment agent (Daravair) and water (tap) is measured. Using a commercial kitchen mixer (Thunderbird Arm-20) the flyash and water/air entrainment is mixed for 3.5 minutes. An Ortho Heavy Duty sprayer is used to evenly apply the water/air entrainment to the flyash. The even dispersion of water is important so clumping does not occur. Care must be taken in not getting the sides of the mixing bowl or paddle of the mixer overly wet. As soon as the mixture is completely added to the flyash, the mixer and the clock are stopped, and the sides of the mixing bowl and paddle are scraped to ensure no dry mixture is left. The mixer is restarted and the clock continued until 3.5 minutes is timed. Once the mixture has been mixed thoroughly, the flyash mixture is ready to be placed in the mold.

The time from the completion of the mixing process to the brick being ejected from the mold is recorded. The mold-ready flyash is placed into the mold using a scoop to ensure little is wasted and consistency. After each mold is full (a 4-brick mold is used), the tops are scraped to ensure each brick contains approximately the same amount of flyash. A piston is then placed on top and the entire mold-piston combination is placed in the press (ELE International Model SP1383). Using the press's digital readout, the bricks are pressed to the desired pressure (in this case 1800 psi). Once pressed, the mold is taken to another press where the bricks are pushed (ejected) out of the mold. As soon as the bricks are ejected, the time is recorded. The ejected bricks are now ready for curing. Before curing, the brick's weight and dimensions are recorded using the digital scale and a digital caliper.

For best results, intermittent flow steam curing is used for the initial curing period. Curing with a mist of water and elevated temperature (100°F) was tried but did not have the success that steam curing had. For steam curing, the bricks are placed in an insulated chamber and cured for three days (36 hours). The steam is generated using a boiler (Sussman Electric Boiler MBA3) and injected into the chamber through ½" galvanized piping with ¼" holes drilled into the side of the pipe. The temperature of the steam inside the curing chamber is sustained at 155-165°F. Once steam curing has completed, the bricks are air or bag cured according to testing procedure. Air curing is done by placing the bricks in a room for the proper amount of time (7 days for these bricks). Bag curing is done by placing the bricks in a re-sealable (Ziploc) bag for the proper amount of time.

## **Brick Testing Method**

The two major brick property tested in this study are compressive strength and freeze-thaw resistance. The test procedures used were derived from ASTM Standard C67. After curing the bricks, their weight and dimensions are recorded using the same means discussed previously.

For compressive testing, the bricks are tested with the ELE press. A digital read-out on the press is used to record the highest load applied during the test. The amount of time from beginning the test to failure is not less than one minute and no more than 2 minutes per ASTM standard. Once the brick fails the machine is shut down manually and the highest load is recorded. The load is converted to psi (pound per square inch) and then recorded. For a brick to pass the ASTM standard and be classified as a severe weather brick, it must reach a minimum of 3000 psi before failure.

Freeze-Thaw testing is started by submerging the brick in water for no less than 2 hours; any longer than this does not warrant more water absorption. This is done to ensure all bricks contain the same amount of water for testing. The expansion of the ice trapped inside the brick during freezing is what causes the brick to fail during freeze/thaw cycles, so the water absorption must be kept constant. After the 2-hour absorption, the bricks are placed in the freeze-thaw chamber. The freezer (True Freeze T-23F) is controlled by a PLC to regulate temperature and to alarm the completion of a cycle for daily recording and water changing. Using the ASTM standard C 67, the freeze-thaw tests are conducted in a freezer and the bricks are placed in a heated pan to cycle temperature from 15°F to 60°F. Half bricks are used for the test per ASTM standard C 67. The pans containing flyash bricks are taken out of the freezer once each day at the end of a cycle, and the bricks in the pans are manually observed. A physical description is recorded and the water is replaced at the end of the cycle (60°F). The water is replaced daily to remove any particulates that may have fallen off the bricks resulting from testing, and to ensure constant water levels. A brick is considered to have failed the test if the mass loss is more than 0.5% or the brick breaks or cracks. For the brick to be a severe weather brick, it must pass 50 cycles with none of the failure criteria being met.

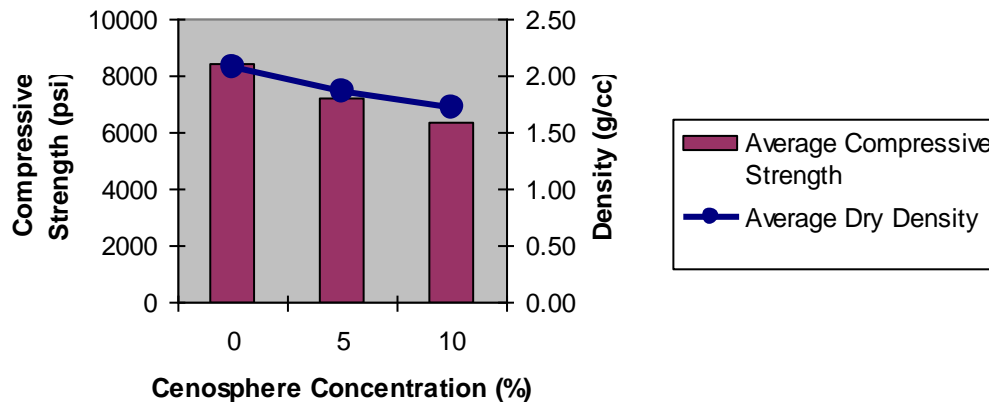
## **Brick Testing Materials**

The materials used to produce these bricks are high grade flyash, tap water, cenospheres and an air entrainment agent. The flyash used in this test is from the Labadie Power Plant in Missouri, which is a large power plant of the Ameren Corporation, using coal mined in the Powder River Basin in Wyoming. The flyash is of high grade containing little (<0.5%) unburned carbon. A ratio of 7.41 was used for the flyash-to-water ratio. The water used is regular tap water. The air entrainment agent used is Daravair. In this study, 0.1% of Daravair was added for the air entrainment agent when used.

Cenospheres are added and measured by % weight. Sphere One Inc. supplied the cenospheres (called extensospheres) used in our testing. Cenospheres are added in various amounts equivalent to 0%, 5%, 10%, and 20% of the dry weight of the flyash.

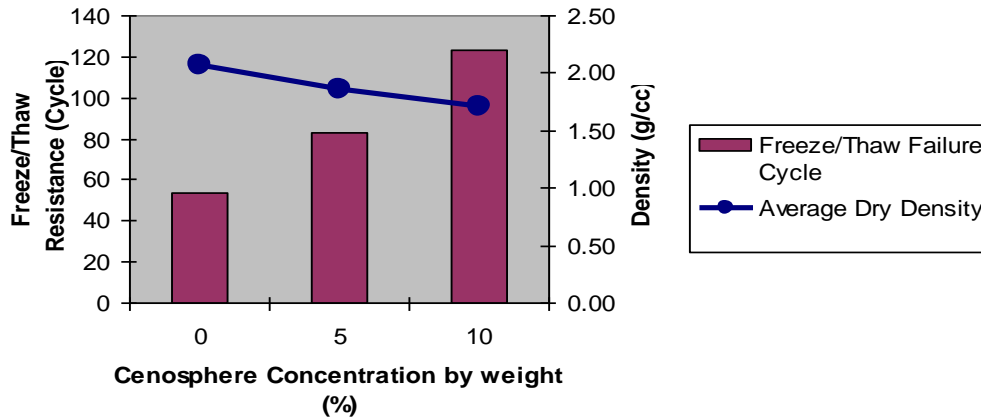
## Brick Test Results

Figure 1 gives the compression strength and the density of the flyash bricks as a function of the cenosphere percentage. The figure shows that as the addition of cenospheres increases, the compressive strength decreases. For this set of the test, the bricks are made without air entrainment. Even at the 10% level of cenospheres, the compressive strength was above 6000 psi, which is double that required by ASTM standard for severe weather bricks. It can also be noted that the density of the brick goes down with the addition of cenospheres in a linear fashion within the test range. The addition of cenospheres allows a lighter brick with an acceptable compressive strength. By adding 10% cenospheres, the brick density reduced from 2.07 to 1.71 g/cc, approximately, which is a 17% decrease in density.



**Fig. 1 Variation of the brick density and compressive strength of bricks with the concentration of Cenospheres.**

Figure 2 gives the freeze/thaw cycles and density of flyash bricks containing cenospheres from 0 to 10%. These bricks contain no air entrainment agent. The number of freeze/thaw cycles passed by these bricks containing cenospheres exceeds the 50 cycles required by ASTM for classification as a severe weather brick. The freeze-thaw cycles increased from 52 cycles for bricks with 0% of cenosphere to 120 cycles for bricks with 10% cenospheres. Also, as the amount of cenosphere increases, the density of the bricks decreases in a linear fashion within the range of data tested.



**Fig. 2 Variation of Density and Freeze/Thaw cycles of bricks with the amount of cenospheres.**

Tests were also conducted using 20% cenospheres and 0.1% air entrainment, under different curing conditions. The initial curing method was moist curing which utilizes a continuous mist of water and a heating element to sustain 105-110°F temperature for 14 days. Before being tested, the bricks were air dried for an additional 7 days after moist curing. The compressive strength test results are still much higher than the required 3000 psi (test data showed 4449 psi average), but cannot be compared directly to the previous graphs due to the difference in curing conditions.

The addition of air entrainment with the cenospheres was tested but the test did not show any performance difference in the freeze thaw resistance. Both bricks with and without the air entrainment agent passed well beyond the 50 (greater than 75) cycles required by the ASTM standard; the test was stopped before the bricks were damaged. This shows that with high amount (20%) of cenospheres, air entrainment is not needed to enhance freeze-thaw resistance.

## Conclusion

As expected, the addition of cenospheres to flyash bricks results in a significant decrease in brick density. For instance, by adding 10% cenospheres, the brick density reduces by 25%. This is beneficial for both financial and technical reasons. The lower weight per brick reduces shipping and labor costs while at the same time allowing greater architectural design flexibility. While the decrease in density does correspond to a decrease in strength, at 20% flyash replacement and 0.1% air entrainment agent addition, the compressive strength was still 4449 psi, which is well above the 3000 psi required by ASTM for severe weather classification.

In addition to the improved freeze/thaw durability and lowered density, the use of cenospheres in flyash bricks is expected to produce other benefits as well such as improved thermal insulating properties. While the technical aspect of adding cenospheres to flyash brick is promising, the current market value of cenospheres makes adding them impractical. In the future as the price of cenospheres decreases, adding cenospheres may become a viable option for producing quality flyash bricks.

The current cost-effectiveness of using cenospheres has been determined as follows[3]: If using 10% cenospheres for making flyash bricks, a ton (2,000 lbs) of flyash needs 200 lbs of cenospheres, costing approximately \$80. Assuming that the flyash costs \$30 per ton (current value of high-quality Class C ash in the Midwest), the total cost of the materials for 2,000 lbs of fly ash plus 200 lbs of cenospheres will be \$110. This amount of materials is estimated to make 500 bricks. This means that the material cost alone for making flyash bricks using 10% cenospheres will be around 22 cents per brick, which is about the same price that ordinary brick manufacturers get for selling an ordinary brick in the wholesale market. No further research has been planned on using cenospheres for flyash bricks until the price of cenospheres is reduced significantly.

At present, cenospheres are used for higher-valued products such as lightweight aggregates in cement, sound proofing, thermal insulation, interior and exterior paints, injection molding of plastics, and automotive brake linings. Desirable properties include controllable density for buoyancy, improved flow, excellent thermal insulation, light weight, and relatively high strength [4].

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