Reducing Embodied Energy in Masonry Construction

Part 2: Evaluating New Masonry Materials

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Environmental performance cannot be the only criteria used to evaluate new products. Since standards development cannot keep pace with innovation of materials, existing standards are good reference points for evaluating new products.

Although environmental criteria are gaining importance to design teams, they cannot be the only criteria used to evaluate new systems. If "green" products do not perform as required for the project, they cannot be used as substitutes for their customary counterparts.

It is the engineer's responsibility to evaluate new materials under consideration for a project. Not only should the structural performance be explored, but also other design criteria, such as aesthetic differences, environmental impact, and interfaces with other materials.

The first part of this series explored the growing importance of embodied energy and carbon footprint in masonry design, along with new products that reduce these impacts (STRUCTURE®, May 2010). In this article, a low-impact product, fly ash brick, will be evaluated in comparison with its traditional counterpart, fired clay brick, demonstrating criteria and methods that can be adapted to an individual project's needs.

Methodology

When designers begin to evaluate a new product, they should ask:

- What are the salient characteristics of the product?
- Is it similar to an existing product?
- Are there existing standards?
- Do the standards make sense for evaluating the new product?

Selecting new masonry materials can be challenging, but familiarity with applicable performance standards can help. Environmental performance information is becoming more available, both from manufacturers themselves and from databases like **www.greenformat.com**.

For this demonstration, the authors selected fired clay brick as the traditional material. It meets the standards of ASTM C 216, *Standard Specification for Facing Brick (Solid Masonry Units Made from Clay or Shale)*, Type FBX, Grade SW, commonly used in commercial projects. The fly ash brick is then evaluated by comparing its properties to those of the fired clay brick.

At least two US companies are developing fly ash brick, and one is already in production. Its fly ash brick consists primarily of Class C fly ash, aggregate, and water. Class C fly ash is a fine powder, captured from the coal combustion process, that reacts with water as a pozzolan. The fly ash binds the mixture as bricks are cured with modest heat and humidity. American fly ash brick is engineered to perform like commercial-quality fired clay brick. It is quite different from the fly ash brick in India and China, where these units are more or less concrete bricks with some fly ash included. For this article, only domestic fly ash brick is considered.

Performance Criteria

Standards development can never keep pace with innovation of materials, but existing standards are good reference points for evaluating new products. For face brick, ASTM C 216 is the accepted standard defining the performance of clay brick; ASTM C1634 *Standard Specification for Concrete Facing Brick* applies to concrete brick. The overlap in performance criteria between these two standards is significant, which is not surprising as they meet the needs of a common application.

Since fly ash brick is not made of clay or concrete, it cannot be said to meet ASTM C 216 or ASTM C1634, which include requirements for both materials and manufacturing methods. However, it can be tested to the same performance criteria. Manufacturers of new materials should be willing to provide test data for their products according to tests that are standard for their traditional counterparts. For this article, a US fly ash brick manufacturer provided such reports from accredited independent testing agencies.

Testing compressive strength of Fly Ash Brick. When evaluating new materials, tests from existing standards can be used.

Design professionals should select materials that perform similarly to their traditional counterparts, or better, for all the performance criteria that matter to the project. In this example, relevant criteria would include compressive strength, freeze-thaw resistance, initial rate of absorption, dimensional tolerance, efflorescence, color stability, and fire resistance. Fly ash brick meets or exceeds industry requirements for fired clay brick.

Compressive Strength

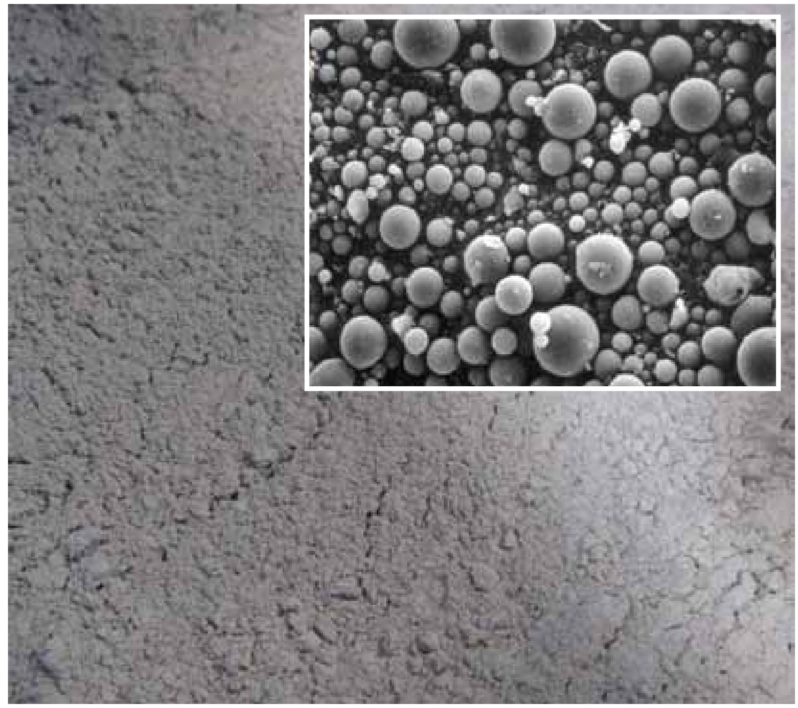
Masonry units are available in many different strengths. When specifying, industry standards are a good place to start, since they set minimum strengths for each grade of product. For some projects, it may be necessary to specify strength beyond the standard of 3,000 psi for Grade SW clay brick. Fly ash brick far exceeds this threshold, averaging over 7,000 psi.

Freeze-Thaw Resistance

Through years of field testing and experience, the clay brick industry has found that bricks with good compressive strength and limited absorption of water will also have good resistance to freezing and thawing. Based on this experience and understanding, ASTM C 216 requires Grade SW clay brick to have an average saturation coefficient of no more than 0.78, with individual bricks limited to 0.80. If a fired clay brick's absorption falls outside these limits, ASTM C 216 requires additional testing for freeze-thaw resistance. The fly ash brick manufacturer has performed direct testing for freeze-thaw resistance according to ASTM C 67, *Standard Test Methods for Sampling and Testing Brick and Structural Clay Tile*. Fly ash brick passes the test for freeze-thaw resistance.

Initial Rate of Absorption

The initial rate of absorption of masonry units needs to be within a certain range to maintain a predictable bond with the mortar. The initial rate of absorption, also called suction, of fired clay brick normally does not exceed 30 g/min/30 in^2. Brick whose suction exceeds this threshold must be wetted before laying. Fly ash brick shows excellent mortar adhesion; its average initial rate of absorption is 1.8 g/min/30 in^2, so wetting is not typically required.



Fly Ash Brick uses Class C fly ash, a coal combustion by-product. Using fly ash in building materials is one of the safest ways to remove it from the waste stream.

Dimensional Tolerance

Brick can be specified according to tolerance, from very precise to intentionally irregular in shape and texture. ASTM C 216 classifies clay bricks by dimensional consistency into three types: Type FBS is standard, Type FBX is precise, and Type FBA is intentionally non-uniform. Fly ash brick is currently manufactured to exceed the rigorous dimensional tolerances of FBX brick, varying no more than 1⁄16 inch in any direction. This makes it both uniform in appearance and easy for masonry crews to lay up efficiently.

Efflorescence

While it does not affect structural performance, efflorescence can be unsightly and can exaggerate the appearance of otherwise harmless moisture in an assembly. ASTM C 216 does not require testing for efflorescence, but offers an optional test. To ensure that efflorescence does not occur, the specifier may require that masonry units receive a rating of "Not Effloresced" according to Test Method ASTM C 67. Fly ash brick meets this requirement.

Color Stability

This aesthetic criterion is important for the service life of the masonry assembly. While clay masonry is generally produced in the natural color of the clay, some fired clay bricks have added pigments, applied either through the body of the brick or on the surface. Fly ash brick incorporates iron oxide pigments meeting ASTM C 979, Standard Specification for Pigments for Integrally Colored Concrete, which measures the color stability of the pigment itself. The pigment extends uniformly through the full body of the brick. Leaching is not an issue for either material, because the pigment is incorporated mechanically in the structure of the unit: fused in the firing of the clay, or bound in the fly ash matrix.

Weathering Change

All surfaces, masonry and otherwise, are subject to weathering, which can change the color and texture of the surfaces. Clay brick assemblies are subject to staining and erosion, while remaining attractive and serviceable; fly ash brick assemblies are likely to weather in the same way. These weathering effects communicate the graceful aging of a structure, and may be considered part of a building's character. Moshe Mostafavi and David Leatherbarrow, in their book *On Weathering: The Life of Buildings in Time*, urge designers to view weathering as the continuous metamorphosis of a building: "Finishing ends construction, weathering constructs finishes."

For this project, Fly Ash Pavers helped meet requirements for recycled content and reduced environmental footprint.

Fire resistance

Fire resistance requirements in building codes are a layered series of requirements. First, combustibility of individual materials is tested according to ASTM E 136, *Standard Test Method for Behavior of Materials in a Vertical Tube Furnace at 750°C*. Once construction materials have been tested according to ASTM E 136 and found to be non-combustible, they may be used in fire-resistive assemblies. Both fired clay brick and fly ash brick are non-combustible. Then, the fire resistance of an assembly is tested according to ASTM E 119, *Standard Test Methods for Fire Tests of Building Construction and Materials*, and results are reported in the number of hours the assembly resists the standard fire. Fly ash brick has been tested according to ASTM E 119 and provides a one-hour fire resistance rating when assembled in a single wythe. When used in other tested assemblies, such as UL's U series of wall designs, either fired clay brick or fly ash brick may be used where "brick" is indicated in the assembly description. Depending on the design, ratings from one hour up to four hours may be available.

Environmental Performance Considerations

When incorporating a new masonry material into a structure, it is important to verify that the project's necessary environmental performance criteria are maintained, or even improved, by the use of the new material.

Many of the performance characteristics recognized in LEED and other rating systems also lead to reduced embodied energy. Though these principles may not be as familiar to structural engineers as structural criteria, they might be required for the project and should be evaluated or tested when considering a new material.

Embodied Energy

The embodied energy of a product consists of the combined energy used to produce, transport, and install the product. Fly ash brick and fired clay brick require the same energy to assemble on site. However, they differ dramatically in their production energy; fly ash brick is produced using only 15% of the energy required for a typical fired clay brick.

Saving transportation embodied energy is one goal of LEED Credit MR 5, "Regional Materials". This credit counts materials produced within 500 miles of the project site, whose raw materials are also extracted within that radius. This credit acts, in part, as a surrogate for calculating the actual transportation energy required for a product. The fly ash brick factory in southeast Wisconsin is within 500 miles of such places as Chicago, Memphis, Pittsburgh, Omaha, Minneapolis, and Toronto. It obtains its materials locally, so projects within 500 miles of this factory may count its brick toward the LEED Credit.

Recycled Content

A good way to reduce embodied energy is to make use of recycled materials. Reclaiming materials from the waste stream saves the energy of extracting and refining virgin materials. Fly ash brick has one of the highest recycled contents among masonry units, consisting of nearly 40 percent fly ash. Fly ash is considered a post-industrial recycled material, so 18.60% recycled content can be applied to LEED Credit MR 4. By contrast, most fired clay brick typically has less than 1% recycled content.

Thermal Performance

Masonry can provide great operational energy performance advantages because of its mass. ASHRAE 90.1 standards and state energy codes provide thermal performance calculations for massive materials, including brick. Using these calculations can, in turn, assist the design team in meeting LEED energy credits or other high-performance building goals. Thermal performance depends heavily on the shape, weight, and configuration of the construction. When designing a massive assembly as a thermal heat sink, it is helpful to compare the specific heat of the new product with the standard product's specific heat. In veneer applications, fly ash brick has a higher insulation value than fired clay brick. Published design R-values, expressed in $hr*ft^2*F°/BTU$, for modular brick are 0.4 for fired clay face brick and 0.92 for fly ash brick.

LEED and Other Rating Systems

If a green building rating system such as LEED applies to the project, part of the evaluation of a new product involves checking it against the targeted goals in the rating system. Some credits depend on a single characteristic of a material, such as recycled content. Other credits may rely on the performance of a complete system, such as heat transmission of a wall, in which the new material may play only one part. Testing the material or assembly may be required as part of the documentation for the rating system.

Masonry assemblies share many characteristics – whether they are made of fly ash brick or fired clay brick – which allow them to contribute to LEED goals. Here are a few of the characteristics and their related LEED credits:

- Durability: Canada LEED Credit MR 8, Durable Building
- Low Sound Transmission: LEED for Schools Credit IEQ 9, Enhanced Acoustical Performance
- No VOC Emissions: LEED Credits IEQ 4.1, 4.2, and 4.6, Low-Emitting Materials
- Breathable Assemblies: LEED for Schools Credit IEQ 10, Mold Prevention

Other Environmental Concerns

Occasionally, new products make the mainstream news over environmental concerns, whether or not these concerns are founded. When considering a new product, it is wise to understand how the layperson might respond to the product's use. These concerns are worth discussing with the manufacturer in order to understand how they are responding to the issues. A responsible manufacturer will commission independent testing to address the concerns and will make the results available to the design team.

For instance, fly ash has been in the news recently because the EPA is considering new rules that might designate fly ash as a special waste when disposed of in impoundments and landfills, to ensure that effective disposal practices in use in some states are applied nationally, and to encourage higher levels of responsible recycling. Beneficial uses such as fly ash brick will remain exempt from regulation under any such ruling, and the EPA has been clear and consistent in its support of such applications. Moreover, fly ash brick is considered an "encapsulated" use because trace heavy metals that might exist in fly ash, similar to the amounts found in other construction materials, are bound within the fly ash matrix that forms as the brick is cured. Neither leaching nor breakage, nor even skin contact, pose health concerns, so both whole fly ash bricks and scrap brick may be handled in the same manner as fired clay brick. When cutting any masonry material, ordinary precautions such as respiratory protection, eye protection, and dust control should be taken.

Compatibility with Related Materials

When evaluating a new masonry material, systems that are in contact with the new material should be carefully considered for compatibility challenges. Predicting potential problems requires a combination of careful analysis and strategic testing.

Standards typically do not address compatibility. Even traditional materials with long histories should be tested in combination with materials applied onto or into the system. It is never sufficient to assume that any product that meets the standard for its type is acceptable for the project, because standards often do not fully address all of the selection criteria.

Systems that interface with masonry assemblies should be analyzed and tested with the masonry materials. Considerations such as corrosion or galvanic reaction with metals, etching of glass, and cleaning methods should be part of the analysis. Pull-out strength and lateral stability should be tested with the intended fasteners. Surface adhesion with sealants and coatings may be another criterion to consider. The more critical the interface is to the integrity of the structure, the more important testing becomes. For instance, both fired clay brick and fly ash brick, along with their mortar, should be tested for compatibility with the following, as they apply to the project:

- Elastomeric sealants
- Waterproofing and flashing materials
- Water repellents and graffiti-resistant coatings
- Cleaning and maintenance materials

New materials, of course, have a shorter history and fewer examples of successful combinations of materials in the field. A responsible manufacturer will have construction trials with common materials and will be willing to share their findings with the design professional. As with any material, it is also important to obtain documentation from the manufacturer or require testing with unusual combinations.

Conclusion

Even when new materials are proposed for sound environmental reasons, such as reducing embodied energy, they must be carefully evaluated. Existing standards may not fully apply to the new materials, but they are useful and necessary to establish performance requirements. When the performance criteria are established independently by the design team, it is within the standard of care to rely upon the manufacturer's literature and testing data to determine whether the new material meets those criteria. However, for critical performance characteristics, the engineer may require supplemental tests or mockups.

Fly Ash Brick demonstrates its mortar adhesion. In product tests, installers found it performed as well as clay brick.

With a clear understanding of the project requirements and their effect on material selection, the structural engineer can play an important role in reducing the embodied energy impact of masonry construction.▪

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