Glass Concrete

Putting sustainability to work in a decorative way

BY CHRISTIAN MEYER

Sustainable development is an emerging political and social issue of global significance. Actually, the concept itself is not new. It dates back to a forester, Hans Carl von Carlowitz of Saxony (1645-1714), who called for the sparing use of trees to give the forest the chance to regenerate and sustain itself. There is an increasing need for the concrete industry to comply with the fundamental goals of sustainable development by reducing its impact on the environment.[1] The key will be targeted research efforts to improve certain properties of concrete products and create new market opportunities. The use of recycled waste glass as concrete aggregate shall serve as an illustrative example of a success story.

Waste glass constitutes approximately 6% by weight of New York City's solid waste, and because it is dirty, of mixed color, and partially broken, secondary markets for it are virtually nonexistent. The use of crushed glass as a concrete aggregate would reduce the amount of solid waste destined for landfill disposal. At the same time, value is added to the glass by its increasing the strength, durability, and, in particular, the aesthetic appearance of the end products.

COMBATTING ASR

It is generally believed that glass is not suitable for use in concrete because alkali in the cement paste may react with the silica in the glass and produce harmful expansion. This alkali-silica reaction (ASR) can occur in concrete produced with many other types of aggregate, and the problem has been studied extensively.[2] Whereas ASR-induced damage caused by most natural aggregates is a long-term phenomenon, which may take years to manifest itself, and is subject to considerable uncertainty, reactions involving the soda-lime glass commonly used for beverage containers are quite certain and comparably rapid.

Rather than yielding to conventional wisdom by avoiding the use of waste glass in concrete, researchers at Columbia University regarded the ASR problem as a challenge to be overcome. In 1995, they initiated a major research project with support from the New York State Energy Research and Development Authority (NYSERDA) to investigate the feasibility of using waste glass in concrete products.[3-5]

Figure 1 illustrates mortar-bar ASR expansions as a function of time and glass content, as obtained in the ASTM C 1260 test. Samples without glass show basically no expansion. Replacing 10% of the natural aggregate with clear glass leads to a 14-day expansion that is twice the ASTM limit of 0.1%, and bars with 100% glass aggregate exhibit the extraordinary expansion of 1.4%. A clear size effect can be detected by replacing 10% of the natural aggregate with an equal amount of crushed glass of a specific size, and plotting the 14-day mortar bar expansions obtained in the ASTM C 1260 test as a function of the glass particle size (Fig. 2). Note the marked pessimum size, which for clear glass is mesh size #16. Also shown in Fig. 2 are the corresponding expansions for amber and green glass. The expansions caused by amber glass are considerably less than those caused by clear glass, and green glass does not appear to cause ASR-induced expansions. This is believed to stem from the chromium oxide manufacturers add to the glass to obtain its green color.[5,6]

When using waste glass as a concrete aggregate, there are several ways to avoid ASR or its damaging effects:

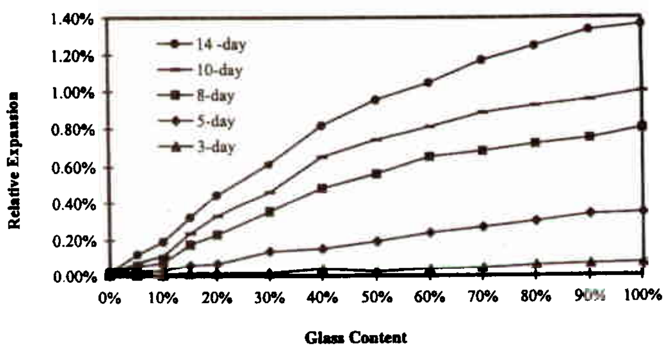

Fig. 1: ASR expansions of mortar bars with different glass contents (ASTM C 1260)

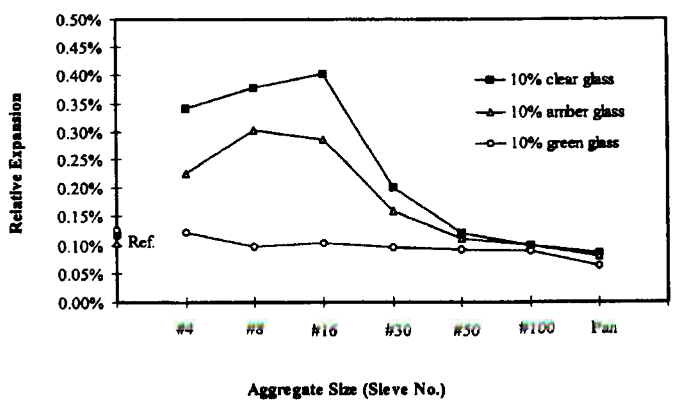

Fig. 2: Glass color and size effect on mortar bar expansions (ASTM C 1260)

- The glass may be ground to pass at least mesh size #50;
- Additions of mineral admixtures, for instance metakaolin or fly ash, are known to effectively reduce expansions;
- The glass can be made alkali-resistant, for example, by coating it with zirconium—a solution chosen by the glass fiber industry, but impractical for post-consumer waste glass;
- Similarly, the glass chemistry can be modified with a view toward recycling, as indicated by the green glass studies;
- Because ASR needs three factors to thrive (alkali, silica, and moisture), sealing the concrete to keep it dry or using it in interior dry environments can minimize or avoid the problem; and
- Special ASR-resistant cements may be developed and are already being offered commercially.

BENEFICIAL PROPERTIES OF GLASS

Glass as a material also offers several advantages that can be exploited in concrete products:

- Because it has basically zero water absorption, glass is one of the most durable materials known to man;
- The excellent hardness of glass gives the concrete an abrasion resistance that very few natural stone aggregates can match;
- Glass aggregate improves the flow properties of fresh concrete so that very high strengths can be obtained even without the use of high-range water-reducing admixtures; and
- Very finely ground glass has pozzolanic properties and therefore can serve both as partial cement replacement and filler.

Concrete with glass aggregate is different from regular concrete in several respects. Mixture proportions for concrete products that are mass produced in automated facilities depend on the particular production equipment used. For example, the zero water absorption of glass improves the mixture rheology that influences mixture proportions, whether a dry or wet process is used.

RECYCLING ECONOMICS

When discussing the economics of glass as concrete aggregate, it is useful to draw a distinction between commodity products and value-added products. The main purpose of using crushed glass in commodity products is to divert as much glass as possible from the waste stream into beneficial applications. The markets for commodity products, such as paving stones and concrete masonry units, however, are typically very competitive, with low profit margins. Therefore, the economic benefit of substituting glass for fine aggregate is marginal at best because it is essential that a dependable source of glass be available that is clean, crushed, and graded to specification.

VALUE-ADDED PRODUCTS

In value-added products, the purpose of the glass substitution is to exploit the special properties of the glass and thereby add value to a material that otherwise would be a waste product. If the glass is sorted by color, and this is coordinated with the color of the cement matrix, novel aesthetic effects can be achieved, which can be further enhanced with appropriate surface treatments. Surface textures can range from highly polished surfaces, for example, for tiles or tabletop counters, to exposed aggregate surfaces for building façade elements.

The economic value of the glass depends to some extent on the material it replaces. For example, terrazzo tiles often contain costly natural aggregate such as imported marble chips. But it is possible to produce decorative visual effects with glass that cannot be achieved with any other material. Thus, the end product is basically without competition and, therefore, very attractive for producers and users alike. Glass concrete terrazzo tiles are being manufactured commercially by Wausau Tile, Inc., of Wausau, WI (Fig. 3).

It should also be mentioned that plain glass concrete is just as brittle as regular concrete. For this reason, it may be advantageous to reinforce glass concrete products with either randomly distributed short fibers or, in the case of thin sheets or panels, with fiber mesh or textile reinforcement.

A paving stone with up to 100% glass aggregate is close to being mass-produced. Its appeal lies in its novel colorings and decorative surface textures, which exhibit special light reflections that cannot be obtained with regular natural aggregate. Other advantages include greatly reduced water absorption and excellent abrasion resistance, due to the extreme hardness of glass. The paving stone can also be reinforced with fibers to improve its mechanical properties, especially its energy absorption capacity and fracture toughness. Initial tests have shown that the resistance of the paving stone to freezing and thawing cycles is excellent, with barely any damage after 600 cycles. Figure 4 illustrates a few glass concrete paving stones.

ADDED ARCHITECTURAL APPEAL

Architects appreciate the many novel surface textures and color effects offered by glass aggregate. This is particularly true for exposed aggregate technologies, which have been known in the architectural concrete community for some time. The added value derives from the fact that both regular concrete and waste glass are inexpensive. If used in combination, however, these two component materials can fetch a price that is only marginally controlled by the costs of production. Because most alternative materials are more costly, glass concrete façade elements offer architects and other design professionals considerable flexibility. Several sample textures are illustrated only imperfectly in Fig. 5.

There are numerous other promising applications in the architectural and decorative fields. It is possible to engineer the material's mechanical and other physical properties to satisfy any reasonable set of specifications.

Fig. 3: Glass concrete tiles

Fig 4: Glass concrete paving stones

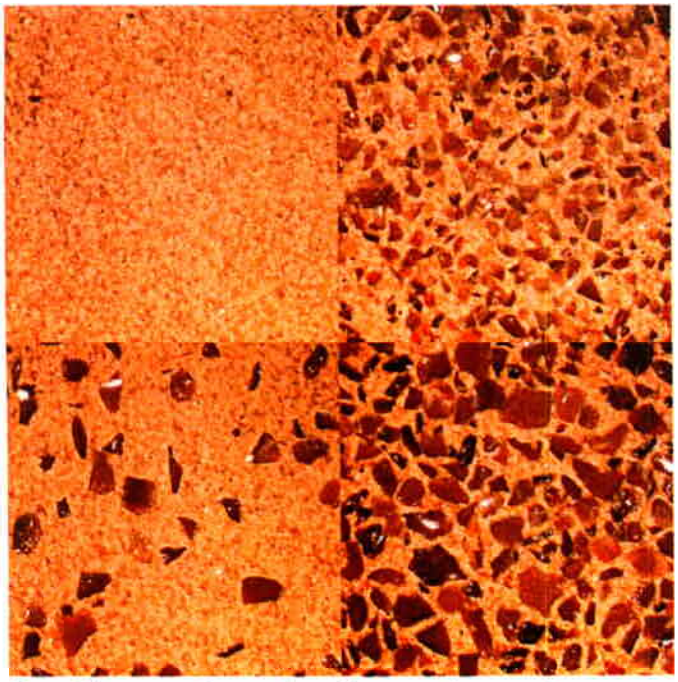

Fig. 5: Glass concrete samples with exposed aggregate

Surface textures and appearances can be created using techniques that are well known in the field of architectural concrete, while fully employing the aesthetic potential of colored glass. The results can be stunning, and the number of potential applications is limited only by one's imagination. To name just a few: building façade elements, precast wall panels, partitions, floor tiles, wall tiles and panels, elevator paneling, countertops, park benches, planters, and trash receptacles.

Although the technical know-how to suppress the detrimental effects of ASR has existed for some time, the use of crushed glass as aggregate is a relatively novel concept. By identifying the special properties of crushed glass and exploiting these in the design of concrete products, it is possible to add value to a material that otherwise would simply be added to the solid waste stream—to be disposed of in landfills.

Such beneficial use of recycled glass offers important advantages:

- The targeted exploitation of glass properties can result in concrete products with characteristics that are superior to those produced with natural aggregates;
- Removal of the glass from the solid waste stream preserves sparse landfill capacity and saves taxpayers the costs of waste disposal. Moreover, such beneficiation of a waste product is compatible with the requirements of sustainable development;
- By adding value to a waste product, both the waste management and concrete industries stand to benefit financially. In some states, developers also can benefit from tax write-offs by using building materials with recycled material content.

Academic research can lead to new technologies. For such technologies to become commercially successful, however, proper technology transfer is needed, as well as adequate funding to make the research effort possible. This requires cooperation between industry and academia. The successful development of glass concrete is an illustration that investment in research does not have to be large to eventually be lucrative.

Acknowledgments

Several present and former staff members and graduate students have made contributions to the work reported in this article—in particular, Semyon Shimanovich, Weihua Jin, and Stephen Baxter.

References

1. Mehta, P. K., "Reducing the Environmental Impact of Concrete," *Concrete International*, V. 23, No. 10, Oct. 2001, pp. 61-66.

2. Bérubé, M. A.; Fournier, B.; and Durand, B., eds., "Alkali-Aggregate Reaction in Concrete," *Proceedings*, 11th International Conference on Alkali-Aggregate Reaction, Quebec City, QC, CRIB, 2000.

3. Meyer, C., and Baxter, S., "Use of Recycled Glass for Concrete Masonry Blocks," *Final Report* to New York State Energy Research and Development Authority, Report No. 97-15, Albany, NY, Nov. 1997.

4. Jin, W., "Alkali-Silica Reaction in Concrete with Glass Aggregate—A Chemo-Physico-Mechanical Approach," PhD dissertation, Columbia University, New York, NY, 1998.

5. Jin, W.; Meyer, C.; and Baxter, S., "'Glascrete'—Concrete with Glass Aggregate," *ACI Materials Journal*, V. 97, No. 2, Mar.-Apr. 2000, pp. 208-213.

6. Baxter, S.; Meyer, C.; and Jin, W., "Use of Waste Glass in Concrete," U.S. Patent No. 5,810,921, U.S. Patent Office, 1998.

Selected for reader interest by the editors.

Christian Meyer, FACI, is a Professor of Civil Engineering at Columbia University in the city of New York. He is a member of ACI Committees 446, Fracture Mechanics; 544, Fiber Reinforced Concrete; 555, Concrete with Recycled Materials (Chair); Joint ACI-ASCE Committee 447, Finite Element Analysis of Reinforced Concrete Structures (Chair, 1981-1985); and the ACI Board Task Group on Sustainable Development. In the past, he has served on ACI Committees 118, Use of Computers, and Joint ACI-ASCE Committee 442, Response of Concrete Buildings to Lateral Forces (discharged).