

Concrete With Recycled Materials



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Introduction

The “greening of concrete” has become a phrase that should by now be quite familiar to all segments of the concrete industry. It refers to the efforts to make concrete, the most versatile and most widely used building material, more environmentally friendly. These efforts pose considerable challenges to the concrete industry, primarily because of the huge amounts of natural resources required each year to produce the over 11 billion tons of concrete worldwide, not to mention the vast amounts of CO₂ released into the atmosphere and energy required to produce portland cement [1]. Owners, developers and architects are increasingly demanding compliance with the principles of sustainable development. For example, more and more of them are requiring that new buildings be LEED-certified [2], which implies, among others, energy-efficient building envelopes, prudent use of water, and the use of recycled materials.

The American Concrete Institute has recognized the importance of these developments for the future of our industry and in response established the Board Advisory Committee on Sustainable Development to coordinate the Institute-wide efforts, as described in a recently published “White Paper” [3]. While this Advisory Committee plays an integrative and general guiding role, specific technical issues are addressed by the pertinent technical committees. A pivotal role is played by Committee 555, Concrete With Recycled Materials. Prior to 2002, the committee was called “Removal and Reuse of Hardened Concrete”. In 2002, its mission was expanded in recognition of the significance the use of recycled materials in general, not only hardened concrete. Within the three years since this reconstitution of the committee, its membership has tripled, which is an indicator of the resonance that these issues are generating in the industry. The committee does not concern itself with recycled cementitious materials such as fly ash, slag, and silica fume, because these important materials are already well covered by other committees.

One of the current activities of Committee ACI 555 is the development of a

state-of-the-art report to inform the industry of the various possibilities of using recycled materials for the production of concrete. A first draft of this comprehensive document is expected to be available later this year. At present it contains the following 11 chapters:

Introduction

Recycled Concrete Aggregate

Use of Waste Glass as Aggregate

Recycled Tires

Pulp and Paper Mill Residuals

Use of Plastics

Foundry Sands and Slags

Manufactured Lightweight Aggregates

Utilization of Wood Wastes

Farm Wastes

Fillers Derived From Dredged Material

Committee ACI 555 sponsored two sessions during the ACI Spring Convention in New York in an effort to acquaint the public with its current activities. Each author responsible for one chapter of the report gave a presentation summarizing the highlights of his respective chapter. The author, Chair of Committee 555, organized the two sessions and, as author of two chapters, made two presentations, summarizing some of the research he had directed at Columbia University during the last ten years. Below, brief summaries of these two presentations follow.

Concrete With Waste Glass as Aggregate

More than 35 billion glass containers are produced in the US, and over 11 million tons of glass are discarded by American households each year. Only about 26% of these amounts are currently recycled, primarily to produce new bottles. The glass industry typically takes back only clear glass for such purposes, whereas most waste glass is not color-sorted. Thus the bulk of the waste glass is typically landfilled, at great cost to taxpayers. In New York City, for example, it is estimated that glass constitutes about 6% of all solid waste, and its disposal costs City taxpayers some \$60 million each year.

There is no shortage of proposals for secondary uses of post-consumer glass. Most of these uses, however, constitute

“downcycling”, i.e. the value of the material is less than in its original form. Examples are uses as “sand” or “gravel”, fill, drainage, filtration, road base and pipe bedding material, and sand blasting. For a while, the City DOT has used some glass in asphalt paving (“glasphalt”), but for various reasons does no longer do so.

Alkali-Silica Reaction (ASR): The use of glass as an aggregate for concrete has been contemplated already decades ago, but the so-called alkali-silica reaction (ASR) caused an insurmountable problem. ASR is now well known in the concrete industry, as it can occur also with natural aggregates that contain certain kinds of reactive (amorphous) silica. In the presence of moisture, the ASR gel swells and can cause severe concrete cracking.

This is a long-term problem that may manifest itself in concrete after years of apparently satisfactory service. The complexity of this phenomenon makes it difficult to predetermine prior whether or not a specific aggregate is potentially reactive. If soda lime glass, the common material of household and beverage containers, is used as aggregate in concrete, not much uncertainty exists with regard to ASR-induced damage, provided there is sufficient moisture available to drive the reaction.

In fact, because of its high reactivity and relatively simple chemistry, soda-lime glass is an ideal material for basic research of the ASR phenomenon and the development of methods to avoid ASR or to mitigate its

detrimental consequences.

For several years researchers at Columbia University have studied the fundamental aspects of ASR and the effects of glass chemistry [4,5]. In the process, they discovered that finely ground glass powder can be used as a pozzolan to partially replace portland cement. This finding has been confirmed by numerous other researchers. Other important aspects were studied, such as the rheology of fresh concrete and the mechanical and other properties of hardened concrete with glass aggregate.

Figure 1 summarizes the expansions of mortar bars with various percentages of clear glass aggregate, tested according to ASTM C 1260, which sets an expansion of 0.1% as the 14-day limit, beyond which the aggregate is suspected to be reactive. As can be seen, this limit is exceeded by more than factor 2 with only 10% of the aggregate replaced by clear glass.

In Fig. 2, the effects of both the aggregate particle size and the glass color are illustrated. The results indicate the presence of a pessimum particle size, which for clear glass is mesh size #16.

The same graph also demonstrates the large differences in reactivity between glasses of different colors. Clear glass, obtained from Snapple bottles, is clearly the most reactive one, followed by amber glass (from Budweiser bottles), whereas green glass (from Beck’s beer bottles) caused less expansion than even the

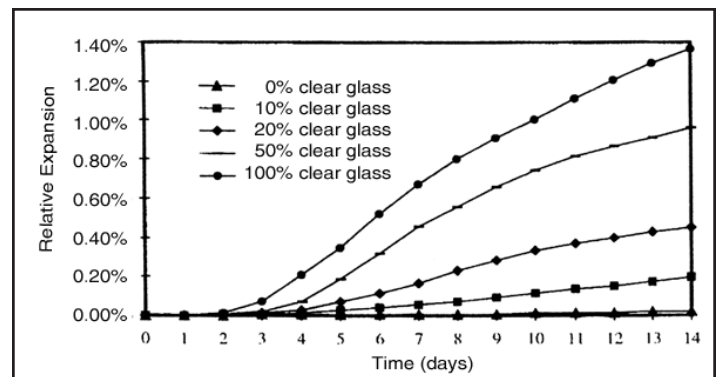


Fig. 1 Expansion of mortar bars with clear glass aggregate

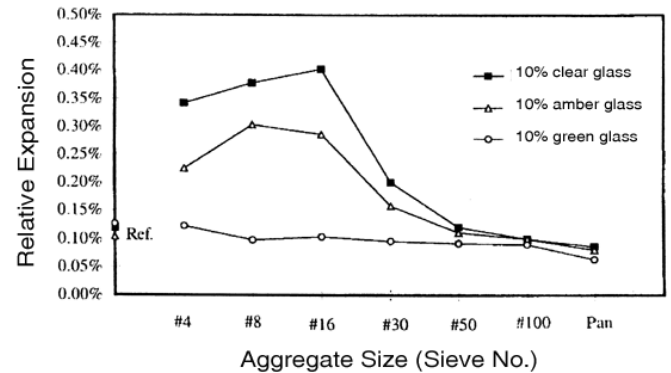


Fig. 2 Expansion of mortar bars with 10% glass aggregate of different size and color

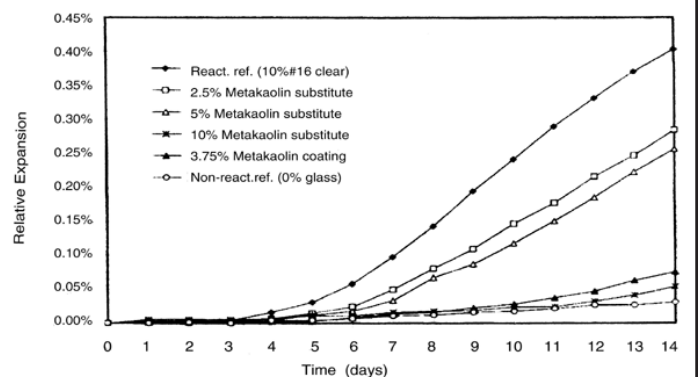


Fig. 3 ASR Suppression Effect of Metakaolin

reference aggregate, a slightly reactive Long Island sand. This surprising finding was explained with the presence of chromium-oxide that manufacturers add for the green color.

There are various tools available to counteract the detrimental effects of ASR. One option is to partially replace portland cement with metakaolin, Fig. 3. The 14-day expansion of mortar bars decreases in proportion to

the metakaolin substitution. However, metakaolin is relatively expensive, if spread uniformly throughout the cement matrix. By coating the glass aggregate with a metakaolin slurry one can assure that the metakaolin is placed only where it is needed, namely in the vicinity of the glass particle surfaces. As Fig. 3 illustrates, 3.75% of metakaolin concentrated in the coating is almost as effective as 10% spread

Continued on page 10

Concrete With Recycled Materials

uniformly throughout the cement matrix.

Since the swelling action of ASR gel is comparable to the pressure generated by freezing free water, an air-entraining agent can reduce the damaging effects of either process.

We can summarize the various means to avoid the damaging effects of ASR as follows:

1. Grind glass fine enough to pass at least US standard mesh #50
2. Use mineral admixtures (metakaolin, fly ash, etc.)
3. Apply protective coating (e.g. zirconium, as for AR glass fibers)
4. Modify the glass chemistry
5. Seal the concrete to protect it from moisture
6. Use a low-alkali cement
7. Develop a special ASR-resistant cement

Advantages. The use of glass aggregate has a number of advantages:

1. Basically zero water absorption
2. Improvement of flow properties
3. Excellent hardness and abrasion resistance
4. Excellent durability and chemical resistance
5. Esthetic potential (color, light reflection and refraction)
6. Pozzolanic properties of glass powder
7. Filler role of glass powder
8. Low cost and wide availability
9. Environmental benefit of adding value to a waste material

These advantages far outweigh the disadvantage of ASR, which can be overcome as mentioned above. Also the smooth surfaces of crushed waste glass have so far not been shown to negatively affect the mechanical properties of the concrete.

Economic Considerations. As is well known, prices are dictated in an open-market economy by the forces of supply and demand. But government has the option of intervening with incentives, in the form of tax write-offs and other benefits, and disincentives, in the form of surcharges, penalties, or outright prohibitions. Also, as the general public is getting increasingly attuned to the principles of sustainable development, society is likely to be willing to pay a premium for environmentally friendly materials and products.

The use of recycled material such as post-consumer glass obviously is associated

with certain costs. These include the cost of collection, cleaning, color-sorting, crushing, grading, and transportation. On the other side of the equation is the large negative cost at the source, i.e. the disposal cost to a municipality, if the glass is not recycled. The economics may be influenced in a decisive way by the value that is added to a material that would otherwise be waste, and by the value of the competing materials or the materials it is meant to replace. By capitalizing on the properties inherent in the glass it may be possible to tip the balance of economics. But, of course, competition (or the lack thereof) and the age-old drive for profit are the other forces that determine economic success or failure.

References

1. C. Meyer, "Sustainable Development and the Concrete Industry", CIB Bulletin, April 2004.
2. U.S. Green Building Council, "LEED Rating System", Version 2.1, Washington, D.C., 2003.
3. Board Advisory Committee on Sustainable Development, "White Paper on Sustainable Development", Concrete International, February 2005.
4. C. Meyer, "Glass Concrete", Concrete International, June 2003.
5. C. Meyer and S. Baxter, "Use of Recycled Glass for Concrete Masonry Blocks", Final Report to New York State Energy Research and Development Authority, Rep. No. 97-15, Albany, New York, November 1997.
6. K. Millrath, S. Kozlova, S. Shimanovich and C. Meyer, "Beneficial Use of Dredged Material", Progress Report Prepared for Echo Environmental, Inc., Columbia University, New York, NY, February 2001.
7. K. Millrath, S. Kozlova, S. Shimanovich and C. Meyer, "Beneficial Use of Dredged Material 2", Progress Report Prepared for Echo Environmental, Inc., Columbia University, New York, NY, December 2001.
8. K. Millrath, "Modifying Concrete Matrices With Beneficiated Dredged Material or Other Clayey Constituents", Ph.D. Dissertation, Columbia University, New York, NY, 2002.

Continued
from page 9