Open-loop Recycling of Glass in Concrete Provides Upcycling Opportunities

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Current Status of Glass Recycling

Due to glass' valuable role in advancing civilization and global sustainability, the United Nations deemed 2022 the "International Year of Glass" [1]. Glass is used intensively. In fact, approximately 12 million tons of waste glass are generated in the United States annually, representing more than 4% municipal solid waste [2].

Unfortunately, on average, just 33% of waste glass is recycled for new glass production in the U.S. [2]. One key challenge to glass recycling is its low monetary value, currently averaging around $11/ton [3].

However, waste glass has an alternative, currently unexploited value: it can be used as a supplementary cementitious material (SCM) in concrete. This brief explores whether the expanded use of waste glass in concrete provides economic and/or environmental benefit.

Key Takeaways:

- Concrete can enable the upcycling of waste glass powder as a pozzolanic material.
- Glass tower buildings can use three times as much recycled glass in their structural concrete compared to their façades.
- The environmental performance of a mixture replacing 20% of portland cement with glass powder is similar to that of the industry average.
- The annual generation of 12 million tons of glass powder can provide a sustainable source of pozzolan (around 12% of portland cement consumption for concrete in the US).
- Due to its availability in urban areas, glass can partially meet the growing demand for supplementary cementitious materials.

More than four percent of the United States' municipal solid waste is waste glass, but just 33% of it is recycled for new glass production. Rather than ending up in landfills, a much more useful purpose for this waste glass is using it as an SCM in concrete. Image source: Fairfax County, VA.

Glass Recycling in Concrete

Historically, crushed glass has been considered a material choice that should be avoided in concrete mixtures as it could act as a concentrated source of alkalis, therefore increasing the risk of the alkali-silica reaction – a deleterious chemical reaction that causes internal swelling and ultimately cracking in concrete [4]. However, over the past two decades, researchers have found that the use of glass powder can reduce the risk of alkali-silica reaction and, more importantly, result in a pozzolanic reaction in concrete [5], [6]. The abundance and potential of this material necessitated the development of standards such as ASTM C1866 [7] for examining and determining the appropriateness of glass powder as an SCM.

Since then, demonstration projects have revealed the positive effect of glass powder on the mechanical performance and durability of concrete mixtures [8]. Case studies in New York City and Montréal suggest that replacing up to 20% of portland cement with a glass powder results in comparable performance to more typical concrete mixtures in both the short and long term [9], [10]. Therefore, glass powder can be a reliable source of SCM that can complement conventional SCMs, such as fly ash and slag.

While using glass powder as a pozzolanic material appears to be a viable option, more information is needed on what recycling pathway can produce the greatest global warming benefit and to what extent using recycled glass in building elements can incentivize the circular economy. To do this, we perform an analysis comparing the benefits of using recycled glass in concrete versus new windows. In this brief, we also evaluate two case studies of concrete buildings to answer these questions.

Waste glass can be recycled into the façades of glass towers, but three times as much of it can be used in the towers' structural concrete.

Evaluating the Environmental Impact of Glass in Buildings

To understand the amount of concrete and glass used in buildings, we examined two cases of a 12-story glass tower (Figure 1.a) and a typical office building (Figure 1.b). In this glass tower, the façade surfaces are completely covered with double-pane windows while in the typical building, the window-to-wall ratio was assumed to be 0.4.

Concrete mix designs for the base cases (GTower-b and GTyp-b scenarios) were adopted from the industry average environmental product declarations (EPDs) reported by the National Ready Mixed Concrete Association (NRMCA) for the U.S.' Eastern Region [11]. The 5000-psi mix design incorporates a total binder content of 442 kg/m3 (8% fly ash and 14% slag). For the base cases, the greenhouse gas (GHG)

emissions of flat glass windows were calculated assuming a recycled glass content of 24% [2].

We also examined an alternate scenario in which the same buildings had an identical binder content, but 20% of the portland cement had been replaced by glass powder. Additionally, we considered the windows to contain 50% recycled glass, the maximum number suggested by the Glass Packaging Institute (i.e., 50%) [12].

Concrete as an Enabler for the Circular Economy of Recycled Glass

We found that the concrete structure can incorporate three times more recycled glass than façade windows. As shown in Figure 2, 91 and 28 tons of glass were used for the glass tower and typical office buildings, respectively, 50% of which may be recycled content. Significantly, over 3000 m3 of concrete used in the buildings' structural elements can incorporate about 300 tons of recycled glass. Therefore, concrete can provide a means to implement glass recycling at scale without compromising its own mechanical performance and durability.

Currently, over 100 million tons of portland cement are being used for concrete production in the U.S. In light of the industry's carbon neutrality goals [13] and the correspondingly increasing demand for SCMs, the availability of more than 12 million tons of waste glass can be a significant source for supplying future needs. This raises an important question: is using waste glass in concrete environmentally beneficial?

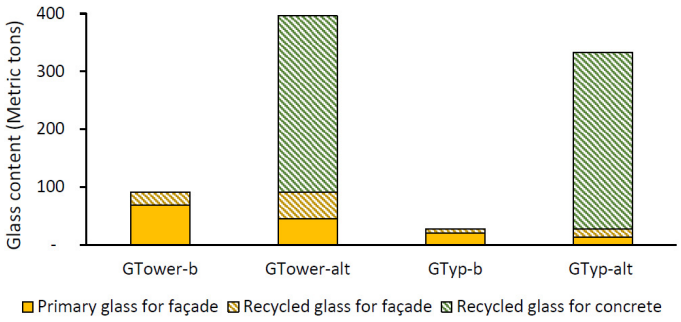

Figure 2. Proportion of primary and recycled glass consumption in each scenario. GTower-b is the glass tower in the base case, GTower-alt is the glass tower in which 20% of the portland cement has been replaced with glass powder and 50% recycled glass was used in windows. GTyp-b is the typical office building in the base case, GTyp-alt is the typical office building in which 20% of the portland cement has been replaced with glass powder and 50% recycled glass was used in windows.

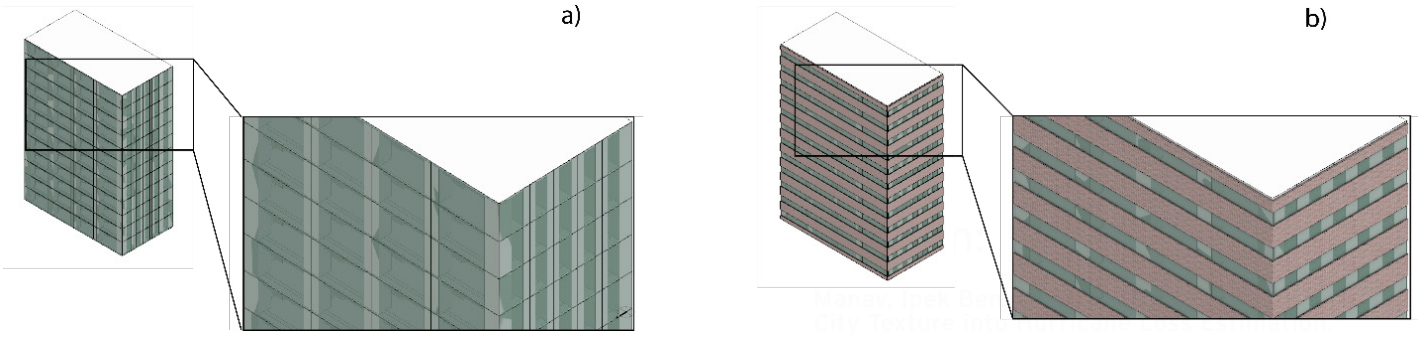

Figure 1. Case studies investigated buildings with a concrete structure for assessing the amount of glass and concrete use in a) a glass tower and b) a typical office building.

Global Warming Benefit of Using Glass Powder in Concrete

Implementing recycled glass into concrete requires a few post-collection processes including transporting glass to the recycling plant, crushing, and micronizing, which consumes heating energy and electricity. However, the amount of energy consumed for glass production is slightly lower than that of slag and similar to that of fly ash (generally, the emissions associated with fly ash are related to transportation activities). As shown in Figure 3.a, the environmental impact assessment of concrete mixtures with 20% glass incorporation is comparable with the industry average one (8% fly ash and 14% slag). Both of these mix designs result in an 18% reduction in the embodied GHG emission of a mixture without pozzolans.

When comparing the GHG savings from one kilogram of recycled glass consumption (i.e., the amount of GHG emissions saved from avoiding portland cement and virgin glass production plus the GHG emissions from recycling activities [12]), using recycled glass as an SCM can provide significantly larger GHG savings (Figure 3.b).

Additionally, the commercial price of glass powder is in line with that of other SCMs. As such, increasing trade with the concrete market should help provide a new revenue stream to the glass recycling ecosystem. Glass powder appears to be a reliable source of pozzolan today and in the future, but local producers should be educated and made aware of the variation in glass quality and properties of glass-incorporated mixtures. As an example, a larger fraction of available waste glass pozzolans comes from container glass that has a high alkali content (compared to other types, such as e-glass). Although the incorporation of glass powder from recycled containers into concrete provides durability and strength benefits, it requires manufacturers to use this SCM with other low-alkali SCMs to ensure the mitigation of alkali-silica reaction. In this sense, education and scaled practices can help avoid unexpected performance issues.

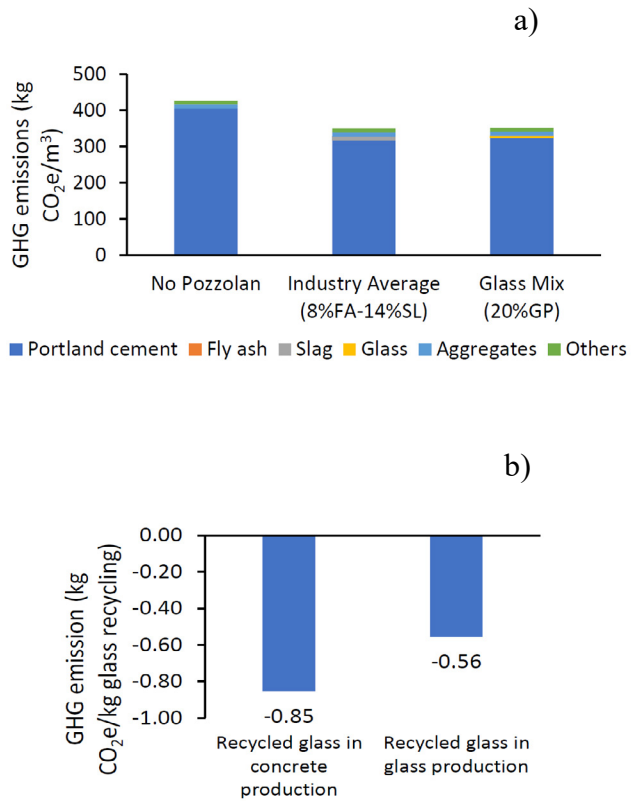

Figure 3. GHG emissions of a) concrete mixtures with no SCM, industry average, and 20% glass powder and b) GHG savings of recycling glass as a replacement of portland cement and window glass (negative values imply GHG savings).

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Related Links:

- MIT CSHub, "Meeting Greenhouse Gas Targets in the Buildings Sector"
- MIT CSHub, "Methods, Impacts, and Opportunities in the Concrete Building Life Cycle

Endnotes

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