The Use of Recycled Glass in Shotcrete

By Isabelle Fily-Paré and Dr. Marc Jolin

Right after the G8 summit in Japan 2008, the International Energy Agency was mandated to work on the development of technology roadmaps meant to identify specific industries and help governments in their quest for sustainable development. The concrete—or more precisely, the cement—industry was identified as an area with high improvement potential. Indeed, cement production is responsible for about 5% of the total CO_2 emitted in the atmosphere around the globe.[1] The reduction of those emissions is not a simple challenge; the cement production process involves both high melting temperatures (2500°F [1400°C]) and the decarbonation of the raw material (such as limestone), each of which is responsible for about half of the greenhouse gas production. The end result is that for each ton of cement produced, almost a ton of CO_2 is also generated.

This leaves us with two simple approaches for reducing the carbon footprint of concrete construction: either modify the cement production process (a task cement producers are actively working on) or, more simply for the end-user, reduce the amount of cement in concrete mixtures.

Food for Thought

Fortunately, brilliant initiatives for partial cement replacement have found success in recent years. It is interesting to see how concrete became a solution for the disposal of many industrial byproducts, such as slag, fly ash, and silica fume. Once costly material to dispose of, these supplementary cementing materials (SCMs) are now regularly included in concrete mixture designs. Their effects on concrete and shotcrete properties, both in fresh and hardened states, are considered very positive. Consequently, many cement producers around the world are now offering preblended binary or even ternary cements.

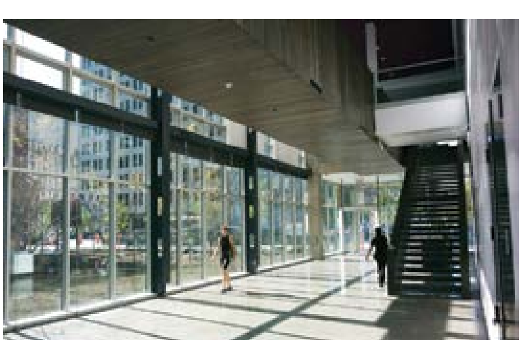

Fig. 1: Centre for Sustainable Development, Montreal (www.maisondeveloppementdurable.org/batiment/choix-ecologique-materiaux)

Naturally, the question is whether or not there are other materials that can be used as cement replacement. A plentiful supply of recycled glass, an environmental issue by itself, has attracted the attention of researchers[2-6] around the world. Published results are very promising, including compressive strength improvement, enhanced durability of certain types of mixtures, and even a water-reducing effect in some cases.

Recycled Glass

The recycling of glass is not as simple as it sounds. It is quite unpopular because of the high costs of transportation and the need to sort the different colors. It is unfortunately often cheaper for cities to send glass waste to landfills instead of paying recycling companies to reinsert it in the consumption loop. As an example, in North America, only 33% of the glass used for glass containers is recycled.[7] Even when glass is collected by a traditional recycling truck, only 40% of the collected glass is recycled.[8] Overall, roughly 13% of glass is truly recycled and the other 87% goes to landfills, even though it would be suitable for a second life. While it may not seem cost-effective to recycle glass, wasting it represents a real problem. In China, for example, the government is considering legislation to make glass recycling mandatory because "glass accounts for 3% of all waste in the cities, and only 5% of it is recycled."[9] The same worries are heard across Europe[10] and Asia.

The Use of Recycled Glass in Concrete

The first trials with recycled glass used it as an aggregate replacement. This approach was highly appreciated by architects because of the special final aspect of the concrete produced. Unfortunately, when glass is crushed in particles larger than 75 µm, it induces alkali silicate reaction (ASR) in concrete.[11] The ASR, often-called "concrete cancer," results in the creation of an expansive (swelling) gel that produces internal cracking in the aggregates and the hardened cement paste matrix. Concrete suffering from ASR exhibits reduced mechanical strength and often severe cracking, which can contribute to accelerated corrosion of embedded steel reinforcement.

Luckily, when the recycled glass is ground into finer particles, it does not create ASR (some studies even suggest that ASR is reduced in the presence of reactive aggregates[12]). Even better, studies have shown that glass powder exhibits pozzolanic activity in which it reacts to form a higher-quality (densified) hydrated cement matrix. Some cases have even shown improved compressive strengths.[2]

Other encouraging studies revealed that glass powder enhances the properties of concrete consisting of fly ash or silica fume. The compressive strengths are higher when glass powder is used with silica fume than when silica fume is used alone.[2] Similar observations have been reported for concrete made with fly ash and glass powder; in this later case, durability was also noticeably enhanced.[13]

Finally, another interesting effect is the water-reducing effect produced when using glass powder. Indeed, despite the high surface area of the glass powder, its surface properties are such that it does not attract water in fresh concrete, leaving more water available for improved workability.[14]

In real life, visionaries have already accepted partial replacement of cement by glass powder. In Montreal, QC, Canada, the designers of the Centre of Sustainable Development have used glass powder for some of their building's concrete. Using this approach helped the building reach a LEED® Platinum certification.[15] The double impact of diminishing the amount of cement in the concrete and avoiding dumping the glass in a landfill has an important impact on sustainability throughout the concrete industry in Canada.

The Use of Recycled Glass in Shotcrete

With its obvious potential, the use of glass powder in shotcrete appears to be an extremely interesting avenue of research. Unfortunately, there are absolutely no studies available about the effect of glass powder in either dry- or wet-mix shotcrete. This subject is, therefore, the focus of a study recently undertaken in the Shotcrete Laboratory at Laval University in Québec City, QC, Canada. In this study, various levels of cement replacement with glass powder (with and without silica fume) are to be evaluated in both shotcrete processes.

Obviously, the hardened shotcrete properties will be evaluated and compared to reference mixtures. However, it is in the placement phase that the effect of the glass powder may have particularly interesting effects, and parameters such as rebound, reinforcing bar encapsulation, and build-up thickness will be evaluated. Early results obtained on dry-mix shotcrete offered some very interesting behavior during the placement phase. It appears that there is a positive effect on rebound reduction and, more importantly, an improved potential for the mixture to encapsulate large reinforcing bars or obstacles. Researchers and industrial partners alike are eager to see more results from this project in the coming months.

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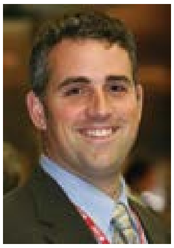
***Isabelle Fily-Paré** received her degree in civil engineering in 2012 from the University of Sherbrooke, Sherbrooke, QC, Canada, and she is now working on her Master's Degree at Laval University, Québec City, QC, Canada. She is currently doing research and development on shotcrete mixes that include glass powder under the supervision of Marc Jolin from Laval University and Arezki Tagnit-Hamou from the University of Sherbrooke. She has also worked on a large hydroelectric dam site in northern Canada where she participated in organizing hundreds of concrete casting and shooting projects.*



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