

An Investigation of Current Status of “Green” Concrete in the Construction Industry

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Concrete is the most largely consumed construction material worldwide. The production of raw materials used in concrete such as Portland cement requires a significant amount of energy input and causes various environmental problems (e.g., emission of greenhouse gases). The “green” concrete in this paper is defined as the concrete produced by utilizing alternative and/or recycled waste materials (such as fly ash and recycled concrete aggregates) to reduce energy consumption, environmental impact, and natural resource use. One of major issues associated with “green” concrete is how the alternative/waste cementitious and aggregate materials affect concrete properties compared with the conventional Portland cement concrete. Another important issue is whether all the benefits and barriers of producing “green” concrete have been adequately understood or addressed. In addition, it is unknown whether a consistent understanding of the current status of “green” concrete exists between academia and industry. This paper first discusses potential benefits of using alternative and/or waste materials in concrete production, followed by a review of previous studies on “green” concrete. The paper further investigates the current status of producing “green” concrete in the construction industry by surveying concrete suppliers/manufacturers in the U.S. The findings presented provide a deeper understanding on the production and implementation of “green” concrete.

Key Words: “Green” Concrete, Supplementary Cementitious Materials (SCMs), Recycled Aggregate, Wastes, Concrete Properties, Construction Industry

Introduction

Concrete is the most widely used construction material in the world (Aitcin, 2000; Mobasher, 2008). It contains four basic ingredients: water, cement, fine aggregate (sand) and coarse aggregate. The manufacturing of traditional concrete using Portland cement (PC) releases a large amount of greenhouse gases such as CO₂ (Meyer, 2005; Bentz, 2010; Bondar et al., 2011). Also, the production of Portland cement is energy-intensive. The use of *supplementary cementitious materials* (SCMs), recycled aggregates and other industrial wastes could reduce the environmental impacts of concrete production (Lepech et al., 2008). In this study, aggregates from recycled waste streams or other non-conventional aggregate materials (e.g., lightweight aggregate) are defined as *alternative aggregate* (AA). The SCMs and AAs are called “green” raw materials in this paper. According to Mannan and Ganapathy (2004), using agricultural and industrial wastes as replacement materials in the concrete industry has dual advantages of cost reduction and a better way of waste disposal. They also pointed out that the material recovery from the conversion of these wastes into useful materials benefits both the environment and the conservation of natural resources.

Although the sustainability of concrete can be improved by using waste materials, adding SCMs or AAs could impact properties of concrete, such as compressive strength, workability, etc., which are extremely important for its applications. Also, production of concrete using waste materials is not necessarily considered sustainable unless the concrete has been proved to be durable (Lepech et al., 2008). Extensive studies have been carried out to identify waste materials that can be used as SCMs and AAs in concrete production. For example, fly ash, blast-furnace slag and pozzolans have been widely identified as SCMs (Topcu and Boga, 2010; Bondar et al., 2011; Limbachiya et al., 2012). Different waste materials that could be potentially used as aggregates have also been explored and concrete properties have been tested (Manso et al., 2006; Polanco et al., 2011; Trussoni et al., 2012). Despite all the efforts in exploring the use of waste materials in concrete, a gap exists between academic research and industry practice. Sometimes materials studied in academic research have critical restrictions that limit their wide applications in the industry. For example, research on *recycled concrete aggregate* (RCA) seems promising by recycling waste

concrete material from demolition (which would otherwise go to landfill) into concrete production. However, inferior quality of this type of concrete such as lower strength has been recognized (Limbachiya et al., 2012).

By adopting a questionnaire survey approach, this study aims to investigate: 1) the current status of “green” concrete production in the industry, 2) identify its benefits and barriers from the standpoint of industry practitioners, and 3) provide the feedback to the academia on how academic research could better match the industry needs. This paper first provides a literature review of previous studies on using SCMs and AAs in concrete production, with a focus on how these “green” raw materials affect concrete properties. Then, the survey results from concrete suppliers/manufacturers are analyzed and discussed regarding the current use of “green” raw materials in concrete production. The ultimate goal of this study is to bridge the gap between academia and industry in their understanding of “green” concrete production and types of waste materials that have broad industry applications.

Background

The potential benefits of using “green” raw materials in concrete production are discussed based on the results from earlier studies. Previous studies on testing mechanical properties of “green” concrete are reviewed. The potential barriers in using “green” raw materials are revealed.

Sustainability in Concrete Production

Aitcin (2000) estimated that 8.4 billion cubic yards of concrete were produced in 1997 worldwide, equivalent to 1.3 cubic yards per person per year. The U.S. concrete production had almost doubled from 220 million cubic yards (431 million tons) per year in the early 1990s to more than 430 million cubic yards (842 million tons) in 2004 (Mobasher, 2008). Concrete production (especially cement manufacturing) consumes a large amount of energy and also has negative environmental impact. As estimated by Meyer (2005), the cement industry alone generates 7% of CO₂ emissions worldwide. Also based on the current technologies, it is technically impossible to lower the energy consumption below the requirement of 3.79 Million Btu per ton. However, in the U.S., about 94 million tons of Portland cement (worth \$9.8 billion) was produced in 2006, most of which was used in concrete (Mobasher, 2008).

Using SCMs and other waste materials in concrete will save energy, protect the environment, and conserve natural resources (e.g., virgin aggregates). According to Malvar et al. (2002), replacing 25% of all cements used in concrete with SCMs could save the U.S. economy more than \$1 billion per year. The results of life cycle inventory from Nisbet et al. (2002) quantified the effects of SCMs on energy saving: One percent replacement of cement with fly ash (one type of SCM from the by-products of coal-fired furnaces at power generation facilities) resulted in 0.7% reduction in energy consumption related to producing cement.

Green Concrete Properties

The replacement of conventional Portland cement with SCMs and the use of AAs in concrete have been studied in the U.S. and worldwide, in particular on how these materials impacted concrete properties. The common SCMs studied include, but may not be limited to, fly ash, furnace slag, and silica fume (Basri et al., 1999; Kevern et al., 2011; Limbachiya et al., 2012). Other researchers have also investigated some AAs, such as tire rubber (Nehdi and Khan, 2001), building rubbles (Khalaf and Devenny, 2004), oyster shell (Yang et al., 2005), waste glass (Berry et al., 2011), RCA (Limbachiya et al., 2012), and waste-expanded polystyrene reground material (Trussoni et al., 2012). Results showed that depending on the type of raw material and percentage of replacement, concrete properties could be enhanced or negatively impacted compared with that of conventional concrete. For example, Basri et al. (1999) found that a higher percentage of fly ash used in the mix reduced the concrete compressive strength. Limbachiya et al. (2012) concluded that 30% of RCA replacement decreased concrete strengths.

Potential Barriers in Implementing “Green” Concrete

Despite the potential benefits from using “green” raw materials in concrete production, there are barriers to the wide application of potential SCMs and AAs. Generally speaking, the barriers exist in concrete properties, cost effectiveness, and industry perception as explained below:

- *Concrete properties:* Using waste streams as concrete ingredients could improve certain types of concrete properties while undermining some others. For example, Yang et al. (2005) found that using crushed oyster shell maintained or improved the compressive strength but decreased the workability. The chemical reaction between silica-rich glass and the alkali was a major concern when using glass in concrete (Batayneh et al., 2007). Concrete containing plastic aggregate decreased compressive and tensile strengths (Siddique et al., 2008). In addition, there generally lacks quantitative data on properties of concrete using waste materials (Duxson et al., 2007).
- *Cost effectiveness:* Cost effectiveness would be the driving force for the industry to implement “green” concrete. Recycling and reuse of wastes requires extra labor and energy input. Batayneh et al. (2007) suggested that the cost between crushing wastes (e.g., glass, plastic and RCA) and supplying prime aggregate (gravel) should be compared in project management. Similarly, Meyer (2009) recommended comparing the transportation cost between RCA from construction & demolition debris and virgin aggregate.
- *Industry perception/practice:* The construction and building product industry is conservative in nature due to the fear of product failure, which becomes a barrier to the utilization of waste materials as pointed out by Duxson et al. (2007). They also indicated the existing negative perceptions of the industry on non-conventional practice in concrete production, which may not be always true. For example, fly ash-contained cement was perceived to have the poor freeze-thaw resistance. Also, the industry tends to follow existing building codes and standards and is resistant to new technologies (Duxson et al., 2007).

Therefore, it is necessary to advance the understanding of concrete properties when using “green” raw materials, reduce potential cost in the recycling and reuse process, improve industry standards, and educate the industry about new technologies.

Research Goals and Methodology

The research presented in this paper aims to investigate the needs of the concrete industry towards environmental sustainability and the current status of “green” concrete production and implementation. The feedback from the industry is very valuable in refining the research problems of “green” concrete in academia and providing researchers with insights on addressing the industry concerns of using “green” concrete.

To meet these goals, this research adopted a questionnaire survey approach to face-to-face interviewing concrete trade association(s), public organization(s), and concrete suppliers/manufacturers in Central Ohio and surveying concrete suppliers/manufacturers from other regions of this country online. Survey questions are centered on: What types of “green” raw materials are being used in the concrete industry? What are the benefits and/or barriers of using them? And what are the other potential “green” raw materials that could be used in producing “green” concrete. The 15 questions in the interview and survey were specified either as multiple-choice or open-ended questions and fell in three parts: survey participants’ and their company’s background information, usage of SCMs within their companies, and usage of AAs. The details of these questions can be found in the results and discussions. Before the interviews and surveys were conducted, the questionnaire was reviewed by a representative from the Ohio Ready Mixed Concrete Association (ORMCA) for its relevance and accuracy to the industry. The feedback was incorporated into the questionnaire. Both the finalized questionnaire and survey procedures were reviewed and approved by the University Institutional Review Board.

Local survey participants (from Central Ohio) were mainly recruited by looking through two publicly available sources: 1) the membership list of ORMCA representing concrete producers and 2) the Membership Directory Book of the Builders Exchange of Central Ohio. The researchers first contacted the selected local companies and explained the purpose of this study and the confidentiality of interview participants. After obtaining their commitment, researchers interviewed one person (recommended by the company to have the best knowledge or expertise in concrete production) per company. The concrete companies for online survey were found through websites of the National Ready Mixed Concrete Association and other trade associations in concrete production/manufacturing and contacted by using their listed email addresses. An on-line survey recruitment script was included in each email. The interviews and online surveys were conducted between July and October, 2012. No identifiable information related to the survey/interview participants was identified in the survey process.

Results and Discussions

In this study, five local concrete suppliers, one organization in the concrete industry (i.e., ORMCA) and one state agency (the Ohio Department of Transportation) were interviewed for their opinions on and experience with “green” concrete production. Of 223 companies invited for online survey, 34 had responded and completed the online questionnaire, representing a response rate of 15%. The survey results obtained through both interviews and online questionnaire were combined in the analysis. The research findings are discussed below in three parts.

Background Information about Survey Participants

The background information regarding the company size, years the company has been in business, and years that the survey respondents have worked in the concrete industry is summarized in Fig. 1. Of the companies in this survey sample, the maximum and minimum years in business are 130 and 6, respectively, with a mean of 50 years. For survey respondents, their maximum and minimum years of concrete industry experience are 44 and 3, respectively. The mean is 23 years.

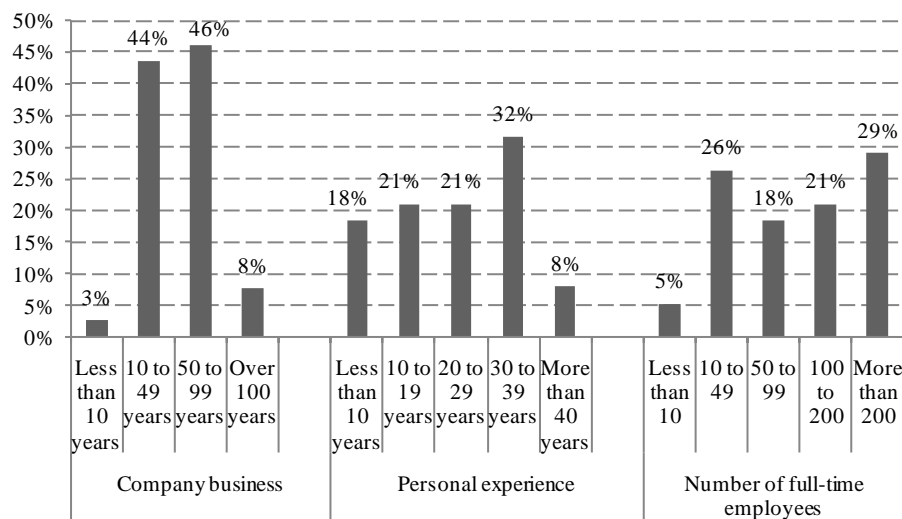


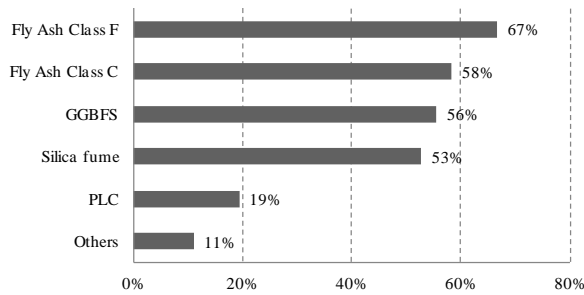
Figure 1. Percentage distribution regarding the background of concrete companies and survey participants (N=39).

The services these companies provide include ready-mix concrete (64% of companies surveyed), prefabricated concrete members (44%), and others (22%) such as quarry or manufacturing of concrete/construction aggregates. It is shown that some companies are providing more than one service (e.g., both ready-mix concrete and aggregates). The similar scenario applies to the questions including what industry sectors these companies’ concrete serves for and what method they use for concrete design. Most companies have their concrete used for the building sector (89%), roadways/bridges (84%), or other sectors (39%) (e.g., industrial and agricultural). When asked what method they use for concrete mixture design, 81% of them responded that they used industry standards and guidelines from the American Concrete Institute, American Society for Testing and Materials, state Department of Transportation, etc. About 68% of them chose using their own companies’ historical data, and 19% mentioned other methods especially the trial batches.

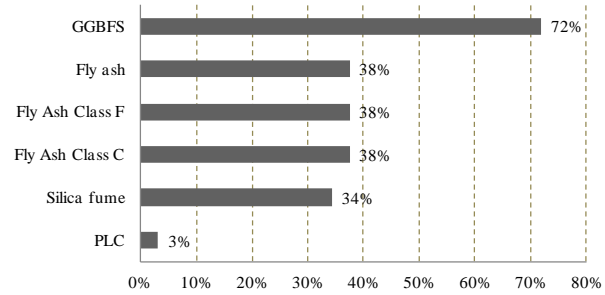
The survey results also showed that 73% of companies had utilized “green” raw materials and 74% of them had received inquiries from customers for “green” concrete. One factor that drove the use of “green” concrete was the Leadership in Energy and Environmental Design (LEED) project requirements as mentioned by some companies.

The Use of SCMs

The second part of the survey asks participants what SCMs are being used in their concrete in a multiple-choice format. Other open-ended questions ask participants what other SCMs could be potentially utilized, what the most commonly used SCMs are, and the advantages or barriers of using them. The percentage of companies, which had used specified type(s) of SCM, is illustrated in Fig. 2a. Each survey participant was also asked to list the top three most commonly used SCMs based on their industry experience. The results are shown in Fig. 2b.



a. Percentage of companies that had used each specified SCM. (GGBFS: ground-granulated blast-furnace slag; PLC: Portland limestone cement) (N=36)

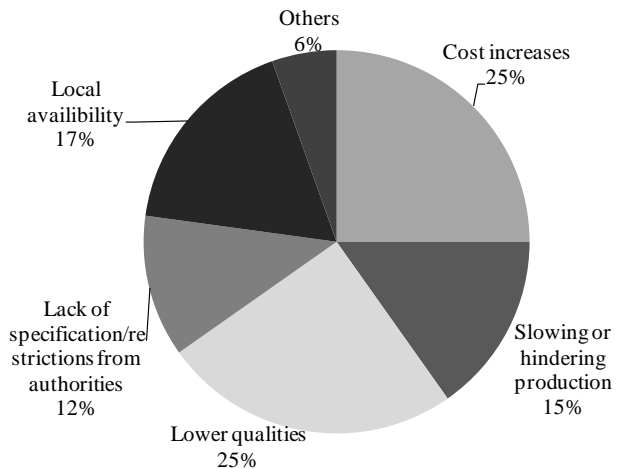
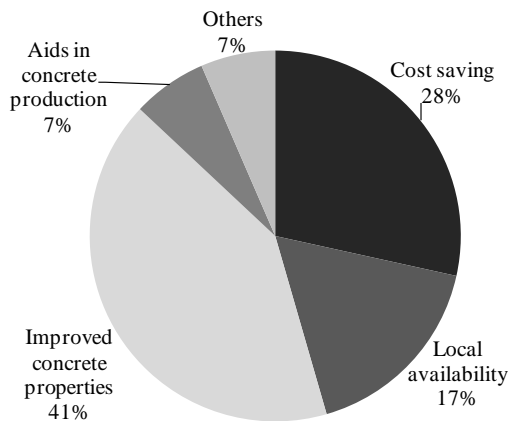


b. Percentage of companies that identified each named material as one of the three most commonly used SCMs in the industry (N=32)

Figure 2. Survey results of industry usage of SCMs.

Fig. 2a shows that fly ash, GGBFS (ground-granulated blast-furnace slag), and silica fume are the three major SCMs currently used in the concrete industry. Participants in the survey also listed some other SCMs they are using, including metakaolin mentioned by two participants and rice hull ash (mentioned once). Some participants in Fig. 2b only answered fly ash but did not specify Class C or F, so “Fly Ash” is listed separately. Therefore, the frequency of fly ash use is greater than GGBFS. When asked what SCMs could be potentially used in the concrete industry, fewer participants (N=17) responded since many companies were not aware of other SCMs. Additional SCMs mentioned were rice husk ash (2 participants), grounded limestone (1), leachates from petroleum waste (1), natural pozzolans (1), ultra fine fly ash (1), metakaolin (1), slag (1), and bottom ash (1). This shows different levels of understanding of SCMs among companies. While some materials such as metakaolin and the rice husk ash have already been used by some companies, they were considered potential SCMs by some other companies. This could be due to the lack of information sharing because companies want to maintain the competitiveness of their business.

For the top three most commonly used SCMs shown in Fig. 2b, participants were further asked for the benefits and barriers of using each of them. The frequency of each item (e.g., cost saving) mentioned by participants was summed up in Fig. 3.



a. Benefits of using the top three SCMs (N=123)

b. Barriers of using these SCMs (N=92)

Figure 3. Benefits and barriers of using the top three SCMs.

The top three most frequently mentioned benefits and concerns from using SCMs were the same: impact on concrete properties, costs, and local availability. Among them, properties of concrete were the most important factor in the consideration of using an SCM. It should also be aware that the advantage of using an SCM for one concrete company could be a disadvantage for another concrete supplier, for example, in terms of local availability. Also, due to the various properties of concrete, one SCM could have both advantages and disadvantages in concrete properties. For instance, an SCM may improve the workability but reduces early strength of concrete. It was worth noting that suppliers/manufacturers were not widely aware of the “green” materials in concrete production as only 2% of them listed that reusing waste materials (which would otherwise be delivered to landfill) is beneficial. Regarding the disadvantages in using SCMs, slowing/hindering production and the lack of specifications or restrictions from authorities (e.g., engineers) were two frequently mentioned barriers besides the top three items.

The Use of AAs

Similar questions were asked in the third part of the questionnaire regarding the usage of AAs as well as the benefits/barriers of using them. Fig. 4 shows the two major AAs being used in the concrete industry: lightweight aggregate and RCA. However, the open-ended feedback from concrete suppliers showed that they were concerned about using RCA in concrete production. The uncertainty in the sources of old concrete made it hard to track the original concrete properties (e.g., strength). There also existed the difficulty in controlling the size of crushed concrete, the inferior engineering properties of RCA due to its higher water absorption and affinity, the lack of specifications, and the risk of quality control from the concrete suppliers’ side. All of these concerns made RCA, seemingly promising in utilizing recycled waste streams to produce new concrete, limited in its applications in the real construction world. Other AAs, such as crushed glass, tire rubber, and brick rubble, although had been studied in academic research, had not been widely used as shown in Fig. 4. When asked about other potential AAs for concrete production, fewer participants could provide feedback: Only cullet pumicite and natural zeolite sludge were mentioned.

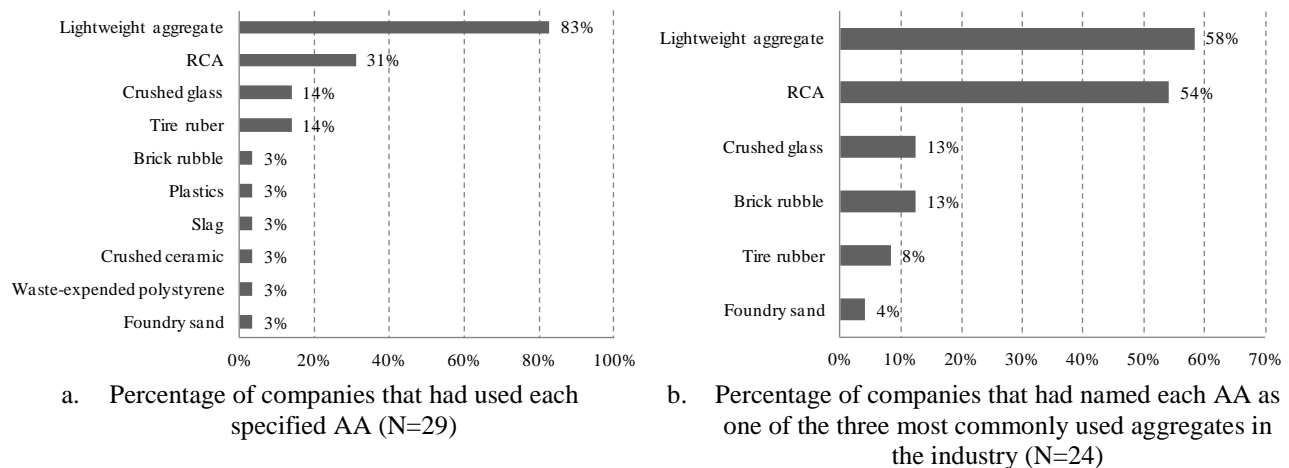


Figure 4. Survey results of industry usage of AAs.

Compared to the advantages and disadvantages mentioned for using SCMs, fewer responses were received for using AAs. The results are illustrated in Fig. 5. It can be seen that the total frequencies of items are 37 and 47, respectively. This could be due to the less knowledge and experience that the concrete industry practitioners have in AAs. There were no specifications mentioned for using AAs, except for lightweight aggregate. This helps explain why lightweight aggregate is currently most widely used. As shown in Fig. 5, the top three benefits and barriers of using AAs are not consistent. The structural advantage and cost savings were widely recognized by the industry. Up to 19% of survey participants knew that using AAs is an approach to being “green.” It could save the natural

resources and reuse waste streams as further indicated by them. However, the technical barriers to using AAs were identified as one of the major disadvantages. These include the difficulty in controlling the AA gradation and the complexity in mix design. In addition, the lack of data on how AAs affect concrete long-term properties was also mentioned as a disadvantage.

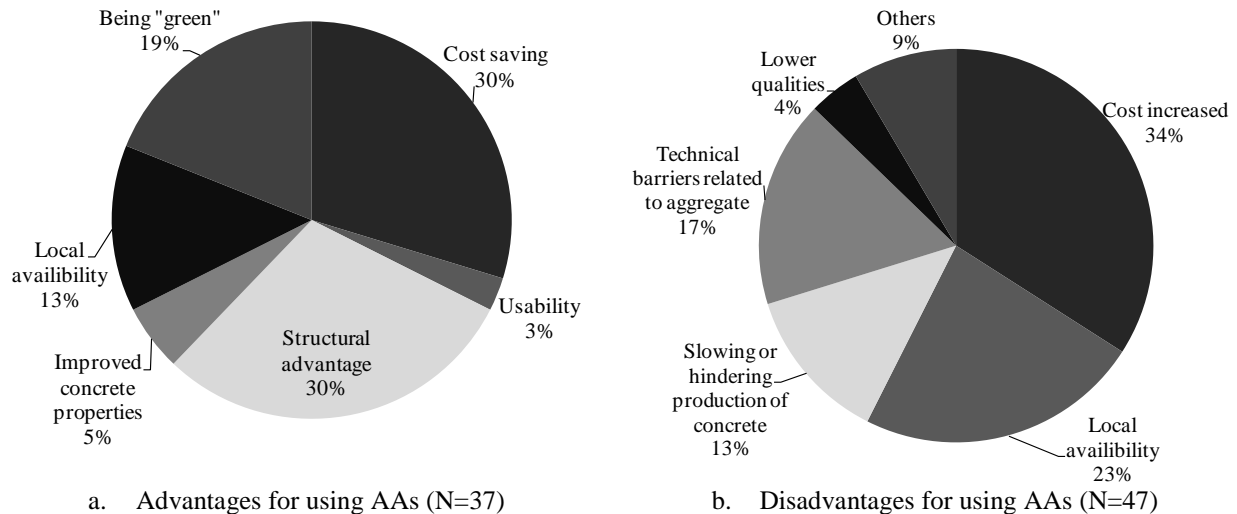


Figure 5. Advantages and disadvantages of using AAs.

The major barriers of using these "green" raw materials (SCMs and AAs) identified in this study are consistent with what have been identified in the literature (see Batayneh et al., 2007; Duxson et al., 2007; Meyer, 2009).

Conclusions and Future Research

This paper presented the survey results on the current status of the "green" raw material usage in the U.S. concrete industry. Despite a large number of academic studies on various types of SCMs and AAs, their current usage in the industry was limited to the top three SCMs as well as lightweight aggregate and RCA for AAs. Also, companies were at different levels in recognizing and utilizing SCMs and AAs. One "green" raw material already used by some concrete companies might still be new to their peers.

Benefits and barriers of using SCMs were basically related to concrete properties, cost, and local availability of such materials. More advantages of using SCMs than disadvantages were mentioned by survey participants. Compared to SCMs, AAs were less commonly used in the industry and survey participants were less knowledgeable in their benefits and barriers. The concept of being "green" through using waste materials had been recognized by some industry practitioners.

Considering the current status of using "green" raw materials in concrete production as well as the benefits and barriers perceived by industry practitioners, academic researchers would need to focus their studies on how the selected SCMs or AAs impact concrete properties, their costs compared with conventional materials, their local availability, and other factors identified in this study. The survey results provide insights and directions on how the academia could help the industry solve its real problems. For example, there is not sufficient data on long-term concrete durability if using RCA. Also, there lack industry standards, particularly on using AAs, which could lead to less acceptance of these "green" raw materials in industry practice.

The survey pool in this study was geographically limited. Future research could expand this study to cover a larger area of the U.S. and potentially Canada. As a result, a more accurate and thorough understanding of the usage of "green" raw materials in the industry would be generated due to the increased sample size and a broader sample distribution.

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