UTILIZATION OF SOLID WASTES (WASTE GLASS AND RUBBER PARTICLES) AS AGGREGATES IN CONCRETE

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Abstract

Post-consumer glass represents a major component of solid waste. On the other hand, more than 100 million tons of coal combustion ash are generated in the U.S. annually, of which 60 million tons are fly ash. To deal with these problems, two new materials were developed: “glascrete” and “ashcrete.” They have the potential of being made almost entirely from recycled materials: crushed mix-color waste glass as aggregate and activated fly ash (or portland cement) as cementitious binder. The combination of waste glass with portland cement or with activated fly ash offers an economically viable technology for high-value utilization of the industrial wastes. Disposal of waste tires is another serious environmental problem in the U.S. Two innovative materials were developed for utilization of rubber particles in concrete: rubber modified concrete (RMC) and sulfur rubber concrete (SRC). In RMC, the strength loss of the concrete is minimized, and the toughness of the concrete is enhanced by surface treatment of the rubber particles using coupling agents. In SRC, waste rubber particles are mixed in sulfur concrete, and the partial vulcanization process between the rubber and hot sulfur improves the strength of SRC.

1. Introduction

Conversion of three types of solid wastes (i.e., waste glass, fly ash, and rubber particles) into construction materials will be discussed in this paper. But, our focus will be made on the utilization of waste glass and rubber particles as aggregates in concrete.

Post-consumer glass represents a major component of solid waste. Current collection methods for glass products are quite limited, therefore, only a small fraction of the solid waste can be recycled directly to the primary market—the bottling and container industry. The problem is very severe in large metropolitan areas such as New York City, Los Angeles, and Chicago. In New York City, for
example, more than 100,000 tons of mixed-color glass is collected annually. This amount does not include the waste glass collected by industrial and commercial companies. On the other hand, the United States generates more than 100 million tons of coal combustion ash annually, of which 60 million tons are fly ash. Only about 27% of the fly ash produced is reused or recycled, and the rest is land filled. Two new materials, called "glascrete" and "ashcrete" were developed to solve the problems. Glascrete has attractive appearance due to the smooth and colorful glass aggregates, which makes it suitable for various architectural and decorative applications. Ashcrete has high strength and very high early strength, which make it unique for applications in precast concrete industry.

The literature review shows that in the waste glass market there are more than 70 potential secondary uses of glass [1, 2, 3]. The most important ones are glasphalt, fiberglass, clean fill, and drainage. There are some advantages for using mixed color glass aggregate in concrete, especially for some architectural applications. However, being a reactive material, when glass aggregates are added into portland cement concrete, they inevitably result in a long-term durability problem, called alkali-silica reaction (ASR). The product of ASR is called ASR gel, which swells with the absorption of moisture. Sometimes the generated pressure due to ASR gel is sufficient to induce the development and propagation of fractures in concrete. Therefore, the major problem that we need to solve for utilization of glass aggregate in portland cement concrete is how to reduce the long-term damage of concrete due to ASR expansion.

Waste tires are another major environmental problem for many metropolitan areas in the U.S. There are more than 242 million scrap tires, approximately one tire per person, generated each year in the U.S. The steady stream of scrap tires, plus 2-3 billion waste tires that have already accumulated in stockpiles and uncontrolled tire dumps, have created a significant disposal problem. In the state of Colorado, more than 2 million waste tires generated per year. It is one of the long-term goals for many state governments to develop more effective uses and markets for the large quantities of waste tires.

Some researchers have tried to use recycled rubber particles as aggregates in portland cement concrete [4, 5, 6, 7, 8]. The advantages of the rubber modified concrete (RMC) can be summarized as (1) The toughness and ductility of RMC are usually higher than that of regular concrete, which makes it suitable for many applications; (2) The density of RMC is lower than the density of regular concrete; and (3) Comparing with other recycling methods, such as using waste tires as fuel in cement plants, RMC makes a fully use of the high energy absorption feature of the rubber particles. The disadvantages of RMC are (1) the strength of RMC is usually lower than the strength of regular concrete; and (2) The durability of RMC is not well understood.
In the following sections, we will introduce most recent research results obtained by several research groups in the United States.

2. Glascrete: Portland Cement Concrete with Waste Glass as Aggregates

The partial replacement of natural aggregate by waste glass in portland cement concrete was studied by Meyer and his co-workers [9, 10]. As mentioned earlier, the main problem to be confronted here is the ASR expansion. The research showed that there are several approaches that can effectively control the expansion of ASR due to glass aggregate, in addition to the conventional approaches used to minimize ASR expansion of regular portland cement concrete, such as using silica fume and various additives.

First, the particle size of glass aggregate was found to have a major influence on ASR expansion. Since the ASR reaction is clearly a surface-area dependent phenomenon, one would expect the ASR associated expansion to increase monotonically with aggregate fineness. However, there exists a size of the aggregate at which the maximum expansion occurs. This is called "pessimum" size. For regular soda lime glass, the pessimum size is about #16 or #30 mesh size. For aggregate finer than the pessimum size, the ASR expansion decreases with further decrease in particle size. In fact, when waste glass was ground to mesh size #50 or finer, no expansion of the glascrete mortar bars was observed. This means that the ASR expansion increases with increasing fineness of glass particles up to a certain point, and then decreases afterwards [11, 12]. The practical implication of this finding is that waste glass, ground to at least mesh size #100, is not likely to cause unacceptable expansion due to ASR.

Types of glass were found to have a significant effect on the ASR expansion. Various types of glass aggregate were tested including soda-lime glass (used in most beverage containers), Pyrex glass, and fused silica. The maximum expansions of mortar bars made with different glass aggregate types differ by almost one order of magnitude. Window glass, plate glass, and windshield glass were found to cause negligible ASR expansion in the ASTM C1260 test.

Colors of glass are also important for ASR expansion. Clear glass (the most common kind in waste glass) was found to be most reactive, followed by amber (brown) glass. Green glass did not cause any expansion. Depending on the size of glass particle, green glass of fine particles can reduce the expansion. This implies that finely ground green glass has the potential for an inexpensive ASR suppressant. The green color comes from added Cr$_2$O$_3$ in the glass. However, when chromium oxide is added directly into the concrete mix, the ASR expansion of the concrete is
not reduced. So, the ASR suppressing mechanisms of Cr₂O₃ in green glass needs to be further studied.

3. Ashcrete: Activated Fly Ash with Glass Aggregates

The glass aggregates were also used in a relatively new cementitious material, called ashcrete, or chemically activated fly ash (CAFA), or water-glass activated fly ash (WAFA) [13, 14, 15, 16]. It is a low-cost and environmentally friendly cementitious material and has great potential for various applications in construction, especially for precast concrete. Ashcrete consists of activation chemicals, Class-F fly ash, coarse and fine aggregates without any portland cement.

![Fig. 1 Ashcrete with 10% glass aggregates, #8 and #16](image)

The same tests for glascrete were performed on ashcrete with the same glass aggregates [15]. Ashcrete binder seems to reduce expansion of ASR. Not only is the maximum expansion of ashcrete much smaller than that of regular concrete, also the expansion time histories for ashcrete exhibit different behavior. For the portland cement concrete (i.e., glascrete), the expansion increases continuously during the 14 day testing period. For ashcrete, almost all curves showed that expansions increase for a certain period and thereafter decrease continuously. After about ten days, the net expansions turned negative, i.e. instead of expanding, the specimens shrank (see Fig. 1).
Experimental investigations similar to those described above for glascrete were conducted for the ashcrete to study the effect of glass particle size, glass type, color and content [15]. The test results showed that (a) unlike in the glascrete, green glass is not effective in suppressing ASR expansion; (b) ashcrete with Pyrex glass or fused silica as aggregate resulted in higher ASR expansion than if window glass aggregate was used; and (c) 100% of natural aggregate can be replaced by waste glass, and the resulting ASR expansion of ashcrete is below the limit of 0.1% considered by ASTM C1260 as critical (see Fig. 2). The most important conclusion is that ASR-related expansion does not appear to be a problem for ashcrete with the waste glass aggregates.

4. Rubber Modified Concrete (RMC)

A systematic experimental study was performed recently for improving strength and toughness of rubber modified concrete [17, 18, 19]. Two types of rubber particles of different sizes (large and small) were used to study the size effect on mechanical properties of RMC (see Fig. 3 for the rubber particles). The average size of large particles is 4.12 mm, and the average size of small particles is 1.85 mm. The test results indicated that particle sizes used in this study has no effect on compressive strength, brittleness and toughness of RMC.
Low water-cement ratio significantly increases the strength of rubber-modified mortars (RMM). An 8% silica fume pretreatment on the surface of rubber particles can improve properties of RMM. On the other hand, directly using silica fume to replace equal amount (weight) of cement in concrete mix has the same effect.

In general, the bond between rubber particles and concrete can be enhanced by increasing electrostatic interactions and/or facilitating chemical bonding. In this study [17, 18, 19], rubber particles were pretreated by coupling agents, and the method was found to be very effective to improve mechanical properties of the RMC. Three coupling agents: PAAM, PVA and silane were tested. Although PAAM is quite effective to improve the interface strength between rubber particles and cement matrix, it has adverse effect on the workability of the RMC when the rubber content is above 10% of total aggregate by volume. Both PVA and silane are very effective in improving the compressive strength of the RMC. There is no adverse effect on workability of the RMC. PVA is more effective than silane for improving the compressive strength of the RMC. The overall results show that using proper coupling agents to treat the surface of rubber particles is a promising technique, which produces a high performance material suitable for many engineering applications.
Fig. 4: Stress-strain curves of the regular concrete (control) and silane-treated RMC (10% rubber content) under compression

Results of tension test, fatigue test and ultrasound velocity test showed that the RMC has higher energy dissipation capacities than regular concrete, that is, the RMC has high toughness and high ductility. Fig. 4 shows that there is a considerable increase in the strain corresponding to the maximum stress, from 0.0034 for regular concrete (shown as “control” in Fig. 4) to 0.0061 for the silane-treated RMC. Also, from the peak stresses and the post-peak curves, one can see that regular concrete is very brittle, and silane-treated RMC is less brittle (i.e. softening behavior). As a result, there is an increase in the toughness and ductility. The failure modes of the RMC indicate that the RMC samples can withhold very large deformation and still keep their integrity.

5. Sulfur Rubber Concrete

Sulfur rubber concrete (SRC) is an innovative idea [17, 20]. In sulfur rubber concrete, melted element sulfur, instead of portland cement, serves as the binder. This is why the concrete is called sulfur rubber concrete, because there is no portland cement in it. Production of sulfur concrete is a hot mix procedure similar to the process for manufacturing of asphalt concrete. Sulfur concrete can be manufactured in a modified asphalt batch plant or a continuous mix facility.

When rubber is used in the sulfur concrete to replace some of the natural aggregates, the hot mix process for the sulfur concrete makes the rubber aggregates undergo a vulcanization process, i.e., reacting to sulfur under temperature about 140°C. Although the reaction kinetics does not allow complete vulcanization happening on the surface of rubber particles under the concrete mixing condition, the sulfur matrix still shows good affinity to the rubber. This characteristic helps to establish a better
bond between the two phases (see Fig. 5) than the bond between rubber and portland cement paste. As a result, the strength of the sulfur rubber concrete is higher than the strength of the regular concrete with rubber aggregates.

For preparing the sulfur rubber concrete, all raw materials, i.e. sulfur, natural aggregates, rubber particles, and mineral fillers need to be heated to 130°C to 146°C. Sulfur rubber concrete is characterized by its high strength, high abrasion resistance and high chemical corrosion resistance. On the other hand, the sulfur cement that bonds the aggregates in the concrete has thermoplastic properties. Consequently, the concrete can be crushed, re-melted and reformed without loss of strength or other properties. In another words, it can be completely recycled. Though its cost of one-time application is higher, the cost for recycling process will be much lower.

In this study, various rubber contents (from 0% to 50% replacement rates of natural aggregate), different micro fillers (fly ash and portland cement), different mixing temperatures, and processing techniques (wet and dry processes) were used for manufacturing of the SRCs. The wet process involves mixing sulfur binder with rubber particles first and holding the mixture at a certain temperature for a period of time. Then, the natural aggregates will be added to the rubber-sulfur mixture. The dry process involves mixing the rubber particles with natural aggregate first and then adding the sulfur binder into the aggregate mixture. The important goal in mix design for SRC is to obtain a proper hierarchical size distribution of all constituent phases. Fig. 6 shows the test data of the study [20]. One can see that fly ash is a better micro filler comparing with portland cement. More importantly, although high rubber content reduces the strength of SRC, the SRCs with rubber content in the
range of 10%-30% have sufficient strength for many applications, provided that proper micro fillers and processing techniques are used.

![Diagram showing the strengths of SRC in terms of rubber contents, types of micro fillers, and processing techniques](image)

**Fig. 6: Strengths of SRC in terms of rubber contents, types of micro fillers, and processing techniques**

### 6. Conclusions

In order to re-utilize solid wastes, such as crushed mixed color glass, fly ash and rubber particles from waste tires, extensive experimental studies were performed for developing four different types of new concretes, glascrete, ashcrete, rubber modified concrete, and sulfur rubber concrete. The experimental results show that each of the concretes has some unique properties, with potentials to be utilized in various applications.

### References