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Impact of combined use of ground glass powder and crushed glass aggregate on selected properties of Portland cement concrete

Kaveh Afshinnia, Prasada Rao Rangaraju *

Glenn Department of Civil Engineering, Clemson University, Clemson, SC 29634-0911, United States

HIGHLIGHTS

- Impact of using large volume of recycled glass in concrete on its properties was evaluated.
- Performance of concrete with glass aggregate was compared to concrete with natural aggregate.
- Use of granular glass aggregate versus fine glass powder on properties of concrete was evaluated.
- Using combination of glass aggregate with glass powder produces strong and durable concrete.

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ABSTRACT

In this study, the impact of using ground glass powder as either a cement replacement material or as an aggregate replacement material on the fresh and mechanical properties of Portland cement concrete were investigated. Also, the synergistic influence of using combinations of glass powder with crushed glass aggregate or natural mineral aggregate on the properties of concrete were investigated. The properties of concrete evaluated in this study include slump (workability), density, air content, compressive and splitting tensile strengths of concrete.

Results from this investigation showed that the workability of concrete was significantly affected depending on whether the glass powder was used as cement or aggregate replacement material, however, air content and density of concrete were affected only when glass powder was used as cement replacement material. In terms of mechanical properties, in the absence of glass powder in concrete, the compressive and splitting tensile strength values of the concrete specimens containing crushed glass aggregate were significantly lower than that of the concrete containing natural mineral aggregate. When glass powder was used as a cement replacement material in concrete, the compressive strength of concrete decreased regardless of the aggregate type. However, when glass powder was used as an aggregate replacement material, the compressive strength of concrete depended on the type containing crushed glass aggregate increased while the compressive strength of concrete containing natural mineral aggregate decreased.

1. Introduction

1.1. Background

According to the Municipal Solid Waste report published by Environmental Protection Agency in 2013, 11.5 million tons of waste glass was produced in the US, a large portion of which is soda-lime glass from container bottles [1]. Although the glass recycling increased from 0.75 million tons in 1980 to more than 3 million tons in 2013 (indicating 26% percent recovered for recycling in 2013), almost 74% of waste glass that is collected is still being disposed in landfills [1]. Some of the difficulties in achieving a complete recycling of waste glass include comingling of different colored glasses at the source as well as difficulty in removing other contaminants such as soil, metals, paper and chemical residues from the waste glass stream. The incorporation of waste glass in concrete in the form of crushed granular material as a replacement for mineral aggregate or as a powdered material as a replacement of Portland cement has been extensively investigated in the past as a solution to manage glass waste [2–15]. However, the susceptibility of glass, particularly soda-lime glass as a granular aggregate, to alkali-silica reaction (ASR) distress has been the main barrier in

* Corresponding author.
E-mail addresses: kafshin@clemson.edu (K. Afshinnia), prangar@clemson.edu (P.R. Rangaraju).

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limiting its widespread use in concrete. Past research on the use of waste glass in concrete has exclusively focused on using the glass either in a crushed granular form or as a finely ground powder form, but never as a combination of these two physical forms in the same concrete. Recent studies by authors showed that the use of finely ground glass powder (with an average particle size of 17 μm) in concrete could substantially alleviate ASR concerns, even when crushed glass was used as an aggregate material [2,3]. This study focuses on evaluating the fresh and hardened properties of concrete employing high levels of waste glass, wherein the glass is used both in the crushed granular form and the finely ground powder form simultaneously.

1.2. Review of literature on the fresh and mechanical properties of concrete containing glass aggregate

Several studies have been carried out to address the fresh properties of mortar or concrete mixtures containing waste glass as aggregate material [4–8]. A study by Ismail et al. was carried out to evaluate the fresh properties of concrete containing glass with a maximum size of 4.75 mm as fine aggregate replacement [4]. It was found that the slump values of the concrete mixtures containing 10%, 15% and 20% glass aggregate decreased by 23%, 30% and 33%, respectively. This progressive decline in the slump values of concrete with increasing levels of glass aggregate was attributed to the poor geometry of glass particles [4]. Also, it was found that the density of fresh concrete mixtures containing 10%, 15% and 20% fine glass aggregate decreased by 1.28%, 1.96% and 2.26%, respectively [4]. A study by Terro was carried out to evaluate the fresh and hardened properties of concrete containing waste glass as either coarse aggregate (with a particle size between 19 mm and 9.5 mm) or as fine aggregate (with a maximum size of 4.75 mm) replacement [5]. It was found that the influence of using less than 25% waste glass in concrete as aggregate replacement was negligible; however, the use of glass as coarse aggregate replacement (at higher dosage level i.e. 50% replacement level) improved the workability of the mixture [5]. This improvement in workability of the mixtures containing 50% coarse glass aggregate was attributed to the poor cohesion between the coarse glass particle and the cement paste [5]. A study by Park et al. was carried out to evaluate the fresh and mechanical properties of concrete containing different proportion of glass aggregate of less than 5 mm in size as fine aggregate replacement [6]. It was found that as the dosage of glass aggregate increased, the slump values decreased and the air content increased. The negative effect of using glass aggregate on the workability of the concrete mixture was attributed to the angular shape of the glass particles (it was found that when 70% fine glass aggregate was replaced as fine aggregate in concrete mixture, the slump value was reduced by 44.3%). The higher level of air content in concrete containing glass aggregate was attributed to the angular shape of the glass aggregate. In terms of hardened properties, it was found that the use of glass aggregate in concrete negatively affected the compressive and tensile strength of the concrete [6]. Also, it was found that the color of glass aggregate had negligible influence on the fresh and hardened properties of concrete, indicating that these properties are governed more by the physical characteristics of glass aggregate particles [6]. A study by Topcu et al. evaluated the fresh and hardened properties of concrete containing waste glass as coarse aggregate (particle size between 4 mm and 16 mm) replacement in concrete mixtures [7]. It was found that by using 60% waste glass as aggregate, the slump values of the concrete mixture decreased by 0.2%. Therefore, they found out that the influence of using coarse glass aggregate on the workability of the concrete mixtures was negligible [7]. It was also found that the air content of the concrete mixtures containing coarse glass aggregate was less than that of the control mixture [7]. The reduction in air content in concrete mixture containing coarse glass aggregate was attributed to the smooth surface of the glass particles, which decreased porosity between glass particles and cement paste. A study by Kou et al. was carried out to evaluate the fresh and mechanical properties of self-compacting concrete containing waste glass (with less than 5 mm particle size) as fine aggregate replacement [8]. In terms of fresh properties, it was found that the use of fine glass aggregate improved the workability of the concrete mixture. This improvement in workability was attributed to the weak cohesion between glass particles and cement paste. However, higher level of segregation was also observed in concrete mixtures containing fine glass aggregate. In terms of hardened properties, it was found that as the dosage of fine glass aggregate in concrete specimens increased, the compressive strength and tensile strength of the concrete specimens decreased [8].

Based on the previous studies, influence of glass aggregate, either as fine aggregate or coarse aggregate, on the workability of the concrete mixtures has not been clearly established. Some of the studies concluded the positive effect of glass aggregate on the workability of the mixture [4,6 and 7], while others concluded the negative influences [5,8].

1.3. Review of literature on the influence of glass powder as a cementitious material in concrete

The influence of glass powder when used as cement replacement on the workability of the concrete mixtures has been evaluated in several studies [9–11]. A study by Shayan et al. showed that the slump values of the concrete mixtures containing 10% and 20% glass powder with an average particle size of 10 μm were 7% and 14% less than that of the control mixtures without glass powder, respectively [9]. A study by Schwarz et al. showed that the slump value of the concrete mixture containing 10% glass powder with average particle size of 25 μm was 21% more than that of the concrete mixture without glass powder [10]. Another study by Taha et al. showed that the slump values of concrete mixtures containing 20% glass powder with an average particle size of 45 μm and control mixture without glass powder were comparable [11]. Based on the previous studies, the influence of glass powder on the workability of the concrete mixtures has not been clearly established. In terms of hardened properties, as soda-lime glass contains significant level of silica (i.e. typically around 70%), when finely ground and used in concrete it can potentially act as a pozzolan, improving the mechanical and durability properties of concrete. However, the fineness of glass powder plays a significant role in its pozzolanic reactivity behavior [2]. Several studies were done to assess the beneficial influence of glass powder as Portland cement replacement in mortar or concrete mixtures [12–19]. Majority of research studies have confirmed that while the glass powder with finer particle size can enhance the properties of concrete, the incorporation of coarser size can increase the likelihood of alkali-silica reaction in such concrete mixtures [20–25]. A study by Ozcan et al. was carried out to evaluate the beneficial effect of glass powder as cement replacement on the compressive strength of mortar mixture [17]. It was found that as the dosage of the glass powder increased, the compressive strength of the mortar cubes decreased. However, the reduction in the strength of glass powder blended mortars was higher at early ages (i.e. 7-day strength) compared to later ages. For instance, while the 7-day compressive strength of the mortar specimens containing 30% glass powder as cement replacement decreased by 19% compared to that of the control specimens, the 28-day compressive strength of the mortar specimens containing 30% glass powder as cement replacement decreased by 15% [17]. The lower strength at early ages was attributed to the lower pozzolanic reactivity of glass powder at early