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Recycled glass fiber reinforced polymer additions to Portland cement concrete

Alireza Dehghan [a], Karl Peterson [a,*], Asia Shvarzman [b]

[a] Univ. of Toronto, Dept. of Civil Eng., 35 St. George St., Toronto, ON M5S 1A4, Canada
[b] Antex Western, 1340 Church Ave., Winnipeg, MB R3C 2L4, Canada

HIGHLIGHTS

- Recycled glass fiber polymers did not cause expansive alkali silica reactions.
- Recycled glass fiber polymers exhibited pozzolanic behavior.
- An absorption test for recycled glass fiber polymer additions is presented.

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ABSTRACT

With recent developments in grinding and sorting technology it is possible to recover glass fibers from waste glass fiber reinforced polymers (GFRPs). The recycled fibers still retain some of the polymer and filler materials, but have the potential to provide some of the same benefits achieved by conventional fiber additions. The research program explored the influence of recycled GFRP on compressive strength, splitting tensile strength, and drying shrinkage in concrete, and alkali silica reaction (ASR) expansion in accelerated mortar beam and concrete prism tests. Compressive strength and drying shrinkage were not improved by recycled GFRP additions at a substitution level of 5 wt% of the coarse aggregate, but splitting tensile strengths were improved in most cases. Negligible expansion was observed from the ASR testing. A scanning electron microscope investigation of the concrete prisms indicated a pozzolanic reaction of the glass fibers.

1. Introduction

Fiber reinforced polymer (FRP) is a composite material which is usually made with glass (GFRP), carbon (CFRP), or aramid (AFRP) fibers dispersed in a thermoset polyester resin and has a wide range of applications in the construction industry. Among GFRPs, E-glass is the most common reinforcement, and represents approximately 99% of the commercial market [1]. The "E" in E-glass is a carryover from its initial application, as used in electrical standoff insulators [2]. The compositional ranges for E-glass used in general applications (such as GFRP) are outlined in ASTM D578 [3] (Table 1).

At the end of the life cycle of FRPs, fibers cannot be easily separated from the resin and the resin itself cannot be easily decomposed or recycled. Hence, landfill and incineration are the most common methods for FRP waste management [4,5]. Globally, GFRP production is estimated at 8 million metric tons annually, with GFRP waste production at 1.5 million metric tons [6]. Given the potential negative environmental impacts of waste FRP, the material has gained the attention of other industries to develop techniques and methods to recycle FRPs. Thankfully, recent advances in grinding and sorting technologies allow for the partial recovery of fibers from FRP and has made their utilization in Portland cement concrete an option. Considering that grinding and sorting equipment are readily available, and that the process produces negligible atmospheric pollution in terms of volatile organic compound emissions, size reduction by mechanical recycling is preferred over other recycling processes [7].

The topic of recycled GFRP in concrete necessarily overlaps with a number of different areas of research, including: glass fiber reinforced concrete (GFRC), waste glass powder concrete, and concrete made using waste plastic fine and coarse aggregate. As such, recycled GFRP combines some of the beneficial aspects of fibers and powdered waste glass, as well as some of the shortcomings of waste plastic aggregates.

* Corresponding author.
E-mail address: karl.peterson@utoronto.ca (K. Peterson).

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Table 1
Certified chemical composition for glass fiber products used in general applications [3].

Chemical	% by Weight
B_2O_3	0–10
CaO	16–25
Al_2O_3	12–16
SiO_2	52–62
MgO	0–5
$Na_2O + K_2O$	0–2
TiO_2	0–1.5
Fe_2O_3	0.05–0.8
Fluoride	0–1

ACI 544.R-96 [8] constitutes a state-of-the-art report on fiber reinforced concrete, with an entire chapter dedicated to GFRC. Fibers in concrete are used to control cracking and to improve tensile and flexural strength. Early formulations of GFRC utilized E-glass fibers, but their use declined after the development of alkali resistant (AR) glass fibers, which performed much better over the long-term in the high-pH environment of concrete pore water. More recently, basalt fibers, made from melting basaltic rock, have been used to produce basalt fiber reinforced concrete (BFRC) [9–11]. In this research, fibers recovered from recycled GFRP are utilized, but the fibers tend to occur in grouped masses bound by residual resin, as opposed to individual clean fibers.

Waste glass is increasingly being utilized in concrete, both as an aggregate and as a powdered pozzolanic addition to concrete. Shi and Zheng [12] provide a thorough review of the topic, and it remains a very active area of research today. However, the majority of the research to date focuses on waste soda lime glass sources from containers or float/plate glass, with relatively few studies on the pozzolanic aspects of recycled GFRP. Xu et al. [13] investigated incinerated waste GFRP from the automotive industry, and used the ash as a pozzolanic additive. Chen et al. [14] investigated the use of ground waste E-glass fibers left over from circuit board manufacture that had never been used in FRP. They documented improvements in compressive strength, chloride and sulfate resistance. Similarly Mastali et al. [15] reported improvements in compressive and flexural strength for recycled glass fibers recovered from woven fiber sheets that had never been used in FRP. However, ground recycled GFRP, a combination of E-glass fibers, resins, and filler materials, is more problematic, as the resins and fillers provide no pozzolanic benefit.

Gu and Ozbakkaloglu [16] conducted an extensive review of the utilization of recycled plastics in concrete from the standpoint of plastic fine aggregate, plastic coarse aggregate, and plastic fibers. While recycled plastic fibers tended to improve mechanical properties of concrete, recycled plastic aggregates led to reductions in compressive and tensile strength, and in most cases increased drying shrinkage.

A common concern with the usage of recycled GFRP in cementitious binders is the potential for interference with the mechanical performance, particularly reductions in compressive strength. The feasibility of recycled GFRP concrete has been explored by a number of researchers worldwide, with a comprehensive review recently provided by Yazdanbakhsh and Bank [17]. Asokan et al. [18] reported reduced compressive strengths with increasing recycled GFRP powder substitution when cured in water at 20 °C, but found increased compressive strengths compared to the control when oven cured at 50 °C. Tittarelli and Moriconi [19] and Tittarelli and Shah [20] reported reductions in compressive strength with recycled GFRP powder additions, but some improvements in terms of reduced drying shrinkage, and lower values for capillary water absorption. Correia et al. [21] explored the use of fines produced during the cutting of pultruded GFRP, and found similar reductions on compressive strength. Osmani [22] also reported reductions in compressive strength for concrete produced with recycled GFRP powder. Alam et al. [23] and Yazdanbakhsh et al. [24] both explored the substitution of larger aggregate sized FRP scrap particles, and reported reductions in both compressive and flexural strength. Alternatively, García et al. [25] explored the use of fibers recovered from recycled FRP, termed “glass fiber fluff,” and reported improvements in compressive and flexural strength when grinding and sieving is optimized.

Expansive ASR is still cited as a concern for concrete as E-glass fibers are not stable in the high-alkali environment of the pore water [26,27]. Meanwhile the potential for powdered waste glass to mitigate ASR has been extensively documented, but not necessarily from the standpoint of waste E-glass [28–41]. Chen et al. [14] found negligible expansion due to alkali silica reaction (ASR) for concrete made with powdered recycled E-glass fibers that had never been used in GFRP. García et al. [25] reported expansions of <0.04% for concrete beams produced with glass fiber fluff recovered from recycled GFRP. Tittarelli and Moriconi [19] tested recycled GFRP powder using the recently withdrawn standard ASTM C289 [42], and found it to be innocuous. However, it is widely recognized that ASTM C289 is not a reliable test for predicting the reactivity of carbonate aggregates [43], and calcium carbonate is a common filler material in FRP.

2. Materials and methods

Descriptions of the commercially produced GFRPs that were investigated in this study are presented in Table 2, and images of the fibers recovered from recycled GFRP are provided in Fig. 1. The recycled GFRP was produced using a model GM-2411-50 ECO Grinder™ [44] single stage hammer mill grinding system with a 19 mm (3/4 in.) screen coupled to a pneumatically fed hopper with a dust collection bag and an enclosed auger feed to a series of 9.5 mm (3/8 in.) and 4.75 mm (3/16 in.) perforated opening trommel (rotary) screens. The GFRP feed consisted of sheets with a maximum thickness of 25.4 mm (1 in.) and nominal dimensions of 150 × 914 mm (6 × 36 in.). Table 3 provides a summary of the wt% glass fiber fluff retained by the screens. Materials separated by both screens were recombined for the purposes of this study. The bottom fines were not included. The results of sieve analyses performed on the combined materials are provided in Fig. 2.

2.1. Water absorption, density, loss on ignition, and fiber cluster length

From each recycled GFRP source three representative samples, each with an approximate mass of 100 g, were produced by the ASTM C702 [45] quartering method for a determination of water absorption. Samples were completely immersed in tap water for 72 ± 2 h and stirred at least once every 24 h for one

Table 2
GFRP types, content, and abbreviations used in this study.

Type	Resin	Glass content (vol.%) as manufactured	Abbreviation
Structural sheet molding composite	Bisphenol-A epoxy vinyl ester	40	EVE1
Structural sheet molding composite	Novolac-based epoxy vinyl ester	40	EVE2
Structural sheet molding composite	Flame retardant epoxy vinyl ester	40	EVE3
Light resin transfer mold	Unsaturated polyester	25	UP
E-glass fiber	None	100	Virgin