Reusing Polymeric Scrap Tire Fibers in Cement Composites: A Novel Material Sustainability Approach

ABSTRACT

The reuse of polymeric scrap tire fibers (STF) as a tire-derived fuel (TDF) is one of the generally adopted waste material reuse and sustainability measures in most developed countries. However, this approach is becoming unpopular given the growing concerns about the release of sulphur-bearing contaminants to the atmosphere during STF combustion. This paper explores the possibility of developing alternative, benign and value-added applications for STF in the construction industry. The effects of STF on the early-age shrinkage and flexural residual strengths of cement mortar mixtures were investigated. Laboratory test results and an ongoing field demonstration project indicate that STF has a huge potential as a discrete fiber reinforcement, especially for applications such as cement repair mortar where plastic shrinkage resistance and residual strength are important considerations.

Keywords: *Fiber; mortar; residual strength; scrap tire; shrinkage and sustainability.*

1 INTRODUCTION

Millions of scrap tires are generated annually in most countries of the world. Hence, scrap tire processing and recycling of by-products resulting thereof, such as crumb rubber and steel wire/fibers has been adopted as an environmental management and material sustainability measures in many developed countries. However, till date, the reuse potential of polymeric scrap tire fibers (STF) has been limited by factors such as uncertain purity as a result of it being an entangled amalgam of polymer/steel fibers, rubber particles and huge variability in dimension.

Given the growing concern for greenhouse gas (GHGs) emissions and their effect on climate change, the use of STF as TDF is not environmentally-friendly because the combustion of crumb rubber particles attached to STF can cause air pollution. According to Levendis (1996), nitrogen oxides (NO_x), sulfur dioxide (SO_2), carbon monoxide (CO) and polycyclic aromatic hydrocarbon (PAH) are emitted during scrap tire combustion. Murena (2000) reported that sulfur-laden gases are produced during scrap tire pyrolysis. Toxic hydrogen sulfide gas was also observed by Tang and Huang (2004) as a major by-product of scrap tire pyrolysis. Hence, to avoid the inherent environmental pollution associated with the combustion of scrap tire particles attached to STF, it is imperative that alternative benign and value-added applications for STF be developed. Utilization of STF as a short, discrete reinforcement in cement-based materials could be one of the potential applications.

In the past few decades, cement and concrete researchers have investigated and successfully utilized low-volume fractions of various types of steel and synthetic fibers as a supplement to the traditional curing approach of reducing plastic shrinkage cracking in cement composites. Najm and Balaguru (2002) reported significant improvement in the plastic shrinkage cracking resistance of cement mortar slabs containing large-diameter sized (0.15-0.64 mm) polymeric fibers at 0.5 to 3% volume fraction. Naaman et al. (2005) investigated the effect of 0.05 to 0.4% volume fraction of various types of synthetic fibers on the plastic shrinkage behavior of concrete, and their findings indicated that 0.2% addition of these fine diameter fibers limited cracking to approximately 10% of those of the reference mixtures. Banthia and Gupta (2006) observed that while 0.1 to 0.3% polypropylene fibers generally improve the plastic shrinkage resistance of concrete, performance was more enhanced in mixtures containing finer and longer fibers.

The use of synthetic fibers in cement matrices has not been limited to plastic shrinkage resistance. Previous studies have also shown that these fibers enhance the mechanical properties of cement composites. Banthia et al. (1994) reported significant toughening, stiffening and strengthening of paste and mortar mixtures containing high volume fractions of carbon, steel, and polypropylene fibers. Research findings by Sivakumar and Santhanam (2007) indicated that even at low volume fraction of 0.5%, the addition of metallic and non-metallic fibers, especially as hybrids to mixtures improve the compressive strength, splitting tensile strength, flexural strength and modulus of elasticity of high strength concrete.

The objectives of this study are twofold; first, the plastic shrinkage resistance and flexural residual strength of cement mortar mixtures containing varying amounts of STF was evaluated. Secondly, real life performance of STF as a discrete reinforcement for a repair mortar was also investigated.

2 METHODOLOGY

2.1 MATERIALS

Ordinary Portland cement (OPC) and natural sand fine aggregate having a specific gravity of 2.65 were used. STF was obtained from the shredding of a mixture of passenger vehicles and truck tires at a Scrap Tire Processing Plant. The average length of STF was approximately 3 – 5 mm.

2.2 MIX PROPORTION & TEST METHODS

Two sets of mortar mixtures were prepared. The first set of mixture with water-to-cement (w/c) ratio and sand-to-cement (s/c) ratio of 0.50, and fiber contents of 0%, 0.2%, 0.3% and 0.4% by mass of cement were used for the plastic shrinkage test. The second set of mixture with a w/c ratio of 0.50, a s/c ratio of 2.0, and 0.35 – 0.7% volume fractions of fibers were used for the flexural residual strength test.

The Environmental Chamber used for the plastic shrinkage test is shown in Figure 1. The chamber measures 1705 mm x 1705 mm x 380 mm, and is equipped with temperature and humidity probes capable of regulating and monitoring the conditions inside. A constant temperature of 50°C± 1°C and a relative humidity of about 5% were maintained inside the chamber using a three heater/blower units (240 volts, 4800 watts with a 1/30 HP, 1550 RPM internal electrical fan). A 60 mm deep mortar overlay was cast and troweled over high strength concrete substrate bases, the substrates and the mortar overlays were transferred to the environmental chamber. After three hours of exposure in the environmental chamber, specimens were de-molded to increase the surface area exposed to drying. Thereafter, specimens were left for an additional 21 hours in the environmental chamber.

Figure 1: Plastic shrinkage test set up

Five prisms from each mixture, measuring 100 x 100 x 350 mm were used for the flexural residual strength tests after 14 days of moist curing. The average residual strength (ARS) of pre-cracked prisms were determined according to ASTM C1399 (2010) specifications. A closed-loop test equipment was used, and during the pre-cracking of specimens, a 12 mm steel plate was placed at the bottom of the specimens to provide support, absorb energy released at cracking thereby limiting the deflection of cracked specimens. Thereafter, the steel plate was removed, and specimens were reloaded under a third-point bending condition, according to ASTM C1609 (2012) test specifications.

3 RESULTS AND DISCUSSION

3.1 PLASTIC SHRINKAGE

Typical crack patterns in specimen reinforced with 0% and 0.4% STF is shown in Figure 2, and it indicate that the addition of STF to mortar mixtures reduces plastic shrinkage cracking significantly. Compared to the large transverse through cracks observed in the reference specimens, STF reinforced specimens seem to have small-sized and segmented multiple cracks. Visual evaluation of specimens shows that none of the specimens containing STF had cracks that were wider than 0.7 mm. The total crack area of specimens is shown in Figure 3, and it indicates that STF was very effective in reducing plastic shrinkage cracking in cement mortar. Compared to the reference specimens, Figure 3 shows that 0.1 - 0.4% addition of STF to mixtures induced approximately 74 – 97.5% reduction in total crack area. The main reasons for the enhanced crack resistance of specimens reinforced with STF are the increased ductility of the mortar matrix and the crack bridging ability of the fibers which limits crack initiation and propagation.

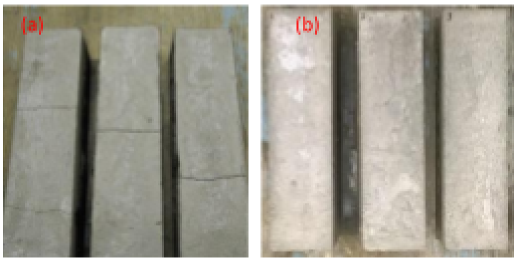

Figure 2: Crack patterns a). Ref and b). 0.4 STF

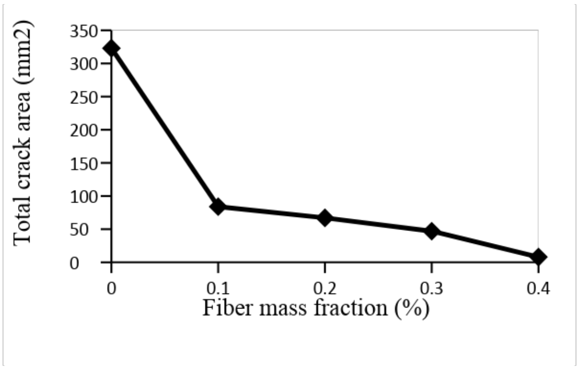

Figure 3: Total crack area in specimen

3.2 Flexural residual strength

The average post-crack load-displacement curves of mixtures are shown in Figure 4. It is very apparent from Figure 4 that while the plain reference mixture recorded no post-crack residual load capacity, slight increases in the residual load bearing capacity of the mixtures reinforced with STF were observed. The ASTM 1399 (2010) average residual strength (ARS) of mixtures were 0 MPa, 0.1 MPa and 0.15 MPa for 0%, 0.35% and 0.7% STF content, respectively. These very low ARS values of the STF reinforced mortar mixtures are as a result of the limited post-crack bridging capacity provided by 3 – 5 mm long STF. As a consequence of this poor residual load capacity, STF reinforced mortar mixtures have limited structural application potentials. However, this drawback could be minimized or eliminated through approaches such as hybridization with longer fibers.

Figure 4: Load-displacement curves of mortar

3.3 ONGOING FIELD APPLICATION

To evaluate the actual performance of STF as a short, discrete reinforcement in cement composites, plain and STF reinforced mortar overlays were used in resurfacing failed sections of the entrance steps of the University of British Columbia (UBC), Canada, MacMillan Building is shown in Figure 5. To monitor the performance of the repair overlay overtime, strain gauges and temperature sensors were embedded in the overlay as shown in Figure 6.

Figure 5: Deteriorated steps at Macmillan Building

The data acquisition system deployed at the project site is shown in Figure 7, and the novelty about this set up is that real-time data acquisition could be monitored wirelessly via cell phone and laptop computer from anywhere in the world.

Figure 6: Data acquisition set up

Figure 7: Data acquisition base station

It is envisaged that research findings from this ongoing pilot study would either give outright validation of STF as a tentative discrete reinforcing material for cement composites, or offer insights on how to enhance the reinforcing potentials of STF. Moreover, this project is also providing the academic research community and the construction industry an opportunity to collaborate on innovative solutions that would have far-reaching environmental and sustainability implications.

4 CONCLUSION

In this study, the effects of STF on the plastic shrinkage cracking and flexural post-crack strengths of mortar were investigated. Based on the experimental results obtained and ongoing field application, the following conclusions are drawn:

- In comparison to the plain unreinforced plain reference mortar, the addition of 0.4% STF to cement mortar reduced plastic shrinkage total crack area by approximately 92.7%.
- Cement mortar containing 0.35% and 0.7% volume fractions of STF had very low post-crack flexural strength, hence these mortar mixtures are unsuitable for any cement-based structural application. Nonetheless, a study investigating the possibility that hybridization of STF with other synthetic fibers could enhance the flexural and residual strength of cement composites is presently in progress.
- The ongoing field application study is highlighting the possibility of using STF as an effective short, discrete reinforcement in cement-based applications such as repair overlays, and hopefully, large-scale utilization of the STF in cement composites in the future will present enormous environmental, economic and infrastructural sustainability benefits.

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