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Structural behavior of rubberized masonry walls

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ABSTRACT

Major environmental problems are resulted worldwide from the disposal of worn out tires that are no longer suitable for use in vehicles. Hence, it is essential to reuse/recycle this waste for clean environment. This paper was carried out to evaluate the effect of recycling scrap tire rubber as aggregate on the properties of solid cement bricks and consequently on the structural behavior of masonry walls under compression. Two sizes of rubber were used to replace conventional coarse and fine aggregates in the production of the bricks. The experimental work was divided into two phases; the first phase included the production of the bricks and investigating their properties. It consisted of twenty-two mixes with 250 and 300 kg/m^3 cement contents. The content of coarse and fine rubber was 0–100% and 0–50% by volume of coarse and fine aggregates, respectively. The second phase included the assessment of the structural behavior of rubberized masonry walls. Eight masonry walls were constructed and tested to evaluate the structural behavior of rubberized masonry walls and their main characteristics. The results indicated that the size and content of rubber have a significant impact on the properties of the bricks and subsequently on the structural behavior of masonry walls. There is a great potential for the utilization of scrap tires in the production of solid cement bricks suitable for use as load bearing and non-load bearing units. This innovative application will open a new field for the recycling of considerable amounts of waste tire rubber for cleaner environment.

1. Introduction

Tire is a composite of complex elastomer formulations, fibers and steel/fiber cord (Siddique and Naik, 2004). Rubber is the principal element of tire where both synthetic and natural rubbers may be used. Rubber is composed of many polymeric repeated units (mainly polybutadiene) chained together. Natural rubber is an elastic hydrocarbon polymer that occurs as a milky colloidal secretion in the sap of several varieties of plants. Synthetic rubber can be produced as a thermoset polymeric material in which individual monomer chains are chemically linked by covalent bonds during polymerization (Peña et al., 2008).

Every year, large numbers of vehicle tires are consumed worldwide causing major environmental problems generated from the disposal of worn out tires which are no longer suitable for use in vehicles due to wear or irreparable damage (such as punctures) (Azmi et al., 2008; Nehdi and Khan, 2001). It is estimated that about 1.5 billions of waste tires are generated globally each year (Malarvizhi et al., 2012). Disposal of discarded tires has been a major concern throughout the world because rubber is not easily biodegradable. The simplest way to get rid of waste tires is by burning, but this method generates toxic fumes that contaminate air, soil and water. Therefore, burning is unacceptable and in some countries it is prohibited by law (Sukontasukkul and Chaikaew, 2005; Torgal et al., 2011). Another easier solution is to leave discarded tires piling up in landfills which indirectly causing significant environmental and human health problems such as being breeding grounds for mosquitoes and rodent that are responsible for the spread of many diseases, in addition to increasing the risk of accidental fires at their storage locations (Ganesan et al., 2010; Garrick, 2005; Skripkiūnas et al., 2007). Tire fires produce a dark smoke that quickly spread causing air pollution and health hazard (Garrick, 2005; Turer, 2012). Open tire fire emissions include pollutants, such as carbon monoxide, sulfur dioxides, oxides of nitrogen, and volatile organic compounds. They also include hazardous air pollutants, such as polynuclear aromatic hydrocarbons, dioxins, furans, hydrogen chloride, benzene and polychlorinated biphenyls. Depending on the length and degree of exposure to tire fire, health hazards could include irritation of the skin, eyes, and mucous membranes, central nervous system depression and cancer (Reisman, 1997). In general, it is very difficult to extinguish tire fires

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because of the void space presenting in the whole tire. A large tire fire can smolder for several weeks or even months (Garrick, 2005). For example, in 1983, a 7-million-tire fire in Rhinehart, Virginia issued a plum of smoke 3000 feet high and nearly 50 miles long with air pollution emissions deposited in three states. The fire burned for nine months polluting nearby water sources (U.S. Environmental Protection Agency, 2013). According to the EU Directive 199/31 EC, the disposal of whole waste tires into the environment is not permitted since 2003 and even the disposal of cut waste tires is not permitted since 2006 (Jevtić et al., 2012). Therefore, there is an urgent need to explore alternative outlets for waste tires, with the emphasis on the recycling philosophy. Recycling of scrap tires on a global scale can drastically reduce waste disposal problems.

Usually, scrap tires are required to be processed before use in alternative applications. The processing includes the cutting of waste tire to the required size and removing of fibers and steel wires. According to Siddique and Naik (2004) that the processed scrap tire particles are classified, based on rubber particle size and geometry, to slit tires, shredded/chipped tires, ground rubber and crumb rubber. Several attempts were carried out to identify the potential applications of waste tire rubber. The most promising applications are: reusing of ground tire rubber in rubber and plastic products as well as in asphalt mixes, thermal incineration of worn-out tires for the production of steam or electricity, and using of tire rubber as fuel for cement kilns, as feedstock for producing carbon black, and as artificial reefs in marine environments (Abduh Dahlan, 2007; Kongsuwan and Phetcharat, 2003; Nehdi and Khan, 2001). The Institute for Environmental Research and Education (2009) reported that the recycling of rubber in plastic products and in asphalt mixes or as energy source creates relatively lower carbon footprint compared to that of most virgin materials for which it can substitute and this is highly favorable from a climate change perspective. In case of using recycled tires as an energy source for the creation of electricity, the life cycle emissions of greenhouse gases generated from tire rubber and coal were 1072 and 1300 g CO_2e/kWh of energy generated, respectively. Energy from recycled rubber has a lower overall carbon footprint than coal. In case of using recycled tires to substitute a portion of asphalt in roads, the carbon footprint for recycling tires was 124 kgCO_2e/metric ton. In comparison, the upstream carbon footprint for the production of asphalt was 840 kgCO_2e/metric ton. The recycling of rubber tires in roads generated almost 7 times less carbon emissions than traditional asphalt. In case of using recycled rubber in plastic products to substitute virgin plastic or as filler, again, the carbon footprint of recycled rubber was between four and 20 times lower than the carbon footprint of virgin resins (The Institute for Environmental Research and Education, 2009).

Waste tires were also investigated to be used as aggregate in concrete (Gomaa et al., 2011; Parveen et al., 2013; Vadivel and Thenmozhi, 2012). It was indicated that the properties of rubberized concrete are greatly affected by the size, shape, and surface texture of rubber particles. Li et al. (2004) investigated the effect of tire rubber source and shape on the mechanical properties of concrete. Two shapes of waste tires (i.e., fibers and chips) were used to replace 15% by volume of gravel. It was reported that concrete specimens with tire rubber fibers have higher compressive strength, split tensile strength and modulus of elasticity than those with tire chips. Using of truck tire fibers is better than using of car tire fibers, and fibers with steel belt wires are better than fibers without steel belt wires. Furthermore, several authors have detected a meaningful decrease in concrete strength with increasing the content of rubber in the mix, regardless of the nature, size and composition of used tire rubber (Peña et al., 2008; Nehdi and Khan, 2001). Antil and Mohali (2014) reported a reduction of 37, 21 and 70% in the compressive, splitting tensile and flexural strengths of concrete by using 20% of fine crumb rubber, while Batayneh et al. (2008) found that the full replacement of fine aggregate by crumb rubber decreased the compressive strength of concrete by 90%. Jevtić et al. (2012) found that the use of rubber to replace 20% of the total aggregate decreased the 28-day compressive and tensile strengths of concrete by 84 and 78%, respectively.

Some authors suggested that the loss in concrete strength might be minimized by prior surface treatment of tire rubber particles. The surface of rubber particles could be generally modified through the treatment with SILAN or immersion in NaOH aqueous solution to increase the adhesion of rubber to the surrounding cement paste (Ghedan and Hamza, 2011; Marques et al., 2008; Reddy et al., 2013). Furthermore, it was reported that silica fume could be used to improve the adhesion between cement paste and rubber particles, which, in turn, enhances the properties of rubberized concrete and decreases the rate of strength loss accompanied by the use of rubber (Güneyisi et al., 2004; Pelisser et al., 2011). However, even after treatment, the strength of rubberized mixes is generally still lower than that of plain mixes. According to Li et al. (2004), the compressive strength of concrete specimens made with untreated and treated rubber by NaOH was 43% and 41%, respectively less than that of unrubberized concrete specimens.

It was reported that although the mechanical properties of rubberized concrete are lower than those of plain concrete, there is some improvement in other properties such as the unit weight, thermal conductivity, sound absorption, freezing-thawing resistance, etc. (Shtayeh, 2007; Siddique and Naik, 2004; Richardson et al., 2012). Sukontasukkul and Wiwatpattanapong (2009) found that the replacement of 30% of fine aggregate by crumb rubber decreased the unit weight and thermal conductivity coefficient of concrete up to 28 and 55%, respectively, depending on the size of crumb rubber, and increased the noise reduction by about 36% compared with plain concrete. In another study carried out by Asphlt Rubber Technology Service (2012), it was reported that using of fine crumb rubber instead of air-entraining admixtures is effective in improving the freeze-thaw resistance of concrete. Skripkiūnas et al. (2007) showed that the addition of 3.2% fine rubber significantly increased the deformation of concrete at failure. Tayeh (2014) investigated the effect of replacing up to 30% of sand by fine crumb rubber on the behavior of concrete beams tested under impact and static bending loads. It was found that although the addition of rubber to concrete decreases its strength under static load, the ability of rubber to absorb dynamic energy enhances the strength of concrete under impact load.

From the above literature survey, it can be found that although rubberized concrete has some desirable characteristics, the significant reduction in compressive strength makes the recycling of waste tire rubber in structural concrete unattractive. Most of researchers recommended the use of rubber in non-structural applications such as architectural applications, partition walls, road barriers, pavement, sound barriers, sidewalks, etc. (Batayneh et al., 2008; Jevtić et al., 2012; Nehdi and Khan, 2001). The aim of this paper is to investigate the possibility of using scrap tire rubber as aggregate in the production of solid cement bricks to be used as load bearing and non-load bearing units. This innovative application will open a new field for the recycling of considerable amounts of waste tire rubber and manufacturing of building material with more versatile performances. Two sizes of rubber were used to substitute coarse and fine aggregates in the production of solid cement bricks. The experimental work was divided into two phases. The first phase included the production of solid cement bricks and investigating the effect of rubber on the physico-mechanical properties of the manufactured bricks, while the second phase