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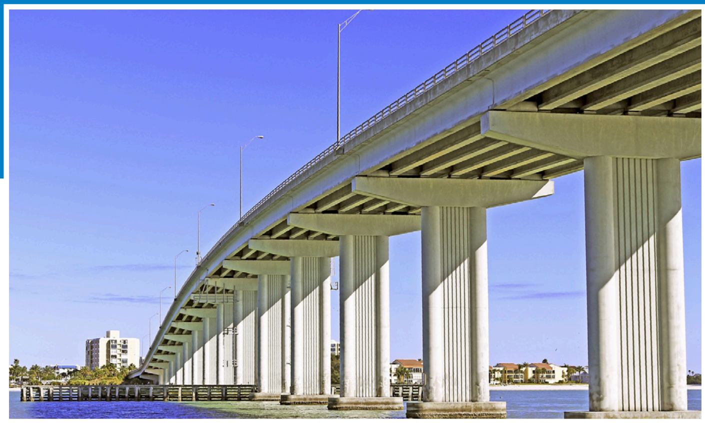

Eco-Efficient and Sustainable Concrete Incorporating Recycled Post-Consumer and Industrial Byproducts

Editor:
Moncef L. Nehdi

SP-314

American Concrete Institute
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Preface

With increasing world population and urbanization, the depletion of natural resources and generation of waste materials is becoming a considerable challenge. As the number of humans has exceeded 7 billion people, there are about 1.1 billion vehicles on the road, with 1.7 billion new tires produced and over 1 billion waste tires generated each year. In the USA, it was estimated in 2011 that 10% of scrap tires was being recycled into new products, and over 50% is being used for energy recovery, while the rest is being discarded into landfills or disposed. The proportion of tires disposed worldwide into landfills was estimated at 25% of the total number of waste tires. Likewise, in 2013, Americans generated about 254 million tons of trash. They only recycled and composted about 87 million tons (34.3%) of this material. On average, Americans recycled and composted 1.51 pounds of individual waste generation of around 4.4 pounds per person per day. In 2011, glass accounted for 5.1 percent of total discarded municipal solid waste in the USA. Moreover, energy production and other sectors are generating substantial amounts of sludge, plastics and other post-consumer and industrial by-products. In the pursuit of its sustainability goals, the construction industry has a potential of beneficiating many such byproducts in applications that could, in some cases, outperform the conventional materials using virgin ingredients. This Special Publication led by the American Concrete Institute's Committee 555 on recycling is a contribution towards greening concrete through increased use of recycled materials, such as scrap tire rubber, post-consumer glass, reclaimed asphalt pavements, incinerated sludge ash, and recycled concrete aggregate. Advancing knowledge in this area should introduce the use of recycled materials in concrete for applications never considered before, while achieving desirable performance criteria economically, without compromising the long-term behavior of concrete civil infrastructure.

Moncef L. Nehdi
Editor

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Mahmoud Reda Taha, Amr S. El-Dieb and Moncef L. Nehdi

Abstract

The disposal of scrap tires has become an international concern. In Canada and the USA, hundreds of thousands of tires have been stockpiled with some authorities banning its landfill. The construction industry can beneficiate substantial volumes of shredded and crumb tire. This article is an overview of recycling tire rubber in concrete. It is shown that concrete with 20-30 *MPa* incorporating crumb and chipped tire rubber particles can be produced with a tire rubber aggregate replacement content less than 20%. Such a rubcrete can have adequate workability and air content, relatively low compressive strength, tensile strength and modulus of elasticity, high impact strength, high ductility and fracture toughness, and reasonable freeze-thaw resistance. The major concern with rubcrete is the significant loss of compressive strength and stiffness at high levels of aggregate replacement with tire rubber particles. However, surface treatments to enhance the bond of tire rubber particles to cement paste represent an efficient approach for enhancing the mechanical properties of rubcrete. Replacing coarse and/or fine aggregate with tire rubber particles results in increasing the strain capacity of concrete. Significant increase in material ductility and ability to absorb energy with increasing tire rubber particle content was reported. It is shown that rubcrete has a clear potential where flexibility and ductility are sought after, for example in tunnel linings, shock barriers, etc.

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Introduction

Recycling waste solid materials has been an international concern considering the unprecedented growth of the world's population, the amount of solid waste generated, and the depletion of waste disposal sites. Scrap tires constitute a large portion of that solid waste and have turned into a worldwide environmental concern. In several countries, scrap tires are being burnt and used as fuel, which is a compromise at best since this practice leads to significant air pollution (Reda Taha et al. 2008). Only a few percentage of scrap tires are being used in or recycled as construction materials.

With the world population exceeding 7 billion people, there are roughly 1.1 billion vehicles on the road, with 1.7 billion new tires produced and over 1 billion waste tires generated each year (Forrest and Rapra, 2014). Specifically, for the fate of scrap tires in the USA, it was estimated in 2011 (Forrest and Rapra, 2014) that about 10% of scrap tires was being recycled into new products, and over 50% is being used for energy recovery (tire-derived fuel (TDF) oil), while the rest is being discarded into landfills or disposed. Worldwide, the proportion of tires disposed into landfills was estimated at 25% of the total number of waste tires (Forrest and Rapra, 2014). Many states (e.g. Ohio) have banned the landfill disposal of whole tires. Scrap tires are sometimes illegally dumped in abandoned buildings and on the landscape (Figure 1) and can present even greater public and environmental health risks. To-date, some of the most important initiatives to reduce the environmental impact of waste tires have been taken in Europe. Other parts of the world are still trying to addressing this issue. For example, in September 2010, China's Ministry of Industry and Information published a new strategic policy document that outlines the future of the country's tire industry (Forrest and Rapra, 2014). In addition to the ever growing shortage of waste disposal sites, stockpiling of scrap tires in landfills can create health and environmental hazards. Possible fires of scrap tires in landfills are an additional reason for banning landfilling of scrap tires (Brown et al. 2001).

Figure 1: Examples of uncontrolled disposal of scrap tires (http://www.edmondok.com/index.aspx?nid=972).

A tire is a composite of plies of rubber elastomer reinforced transversely with steel fibers and cords. Natural rubber, as fabricated in rubber products, combines high strength (tensile and shear) with outstanding resistance to fatigue. Its ability to stick to itself and to other materials makes it simple to fabricate. Rubber has excellent adhesion to brass-plated steel cord, low hysteresis which imparts low heat generation, which in turn maintains new tire service integrity. Thus, tire recycling shall make use of some of these performance attributes.

Some promising options for using scrap tires include incineration of tires for the production of steam and electricity (Fedroff et al. 1996, Siddique and Naik 2004) and the reuse of ground tire in reproducing plastic products. Scrap tires have been used successfully in cement kilns and for artificial reefs (Fattuhi and Clarck 1996). Nehdi et al. (2005) investigated the possible use of tire rubber in flexible mortars used as a lining material for precast concrete tunnels subjected to pressure from time-dependent rock squeeze. It was shown that deformable tire rubber mortar helped to decrease stresses in the tunnel lining system. Possible use of such a material in protective lining systems for underground and buried infrastructure opens a new and wide field. Other successful applications of scrap tires include its use in hot mix asphalt, as a highway construction material in pavements, subgrade insulation, lightweight fill material, and drainage material in flowable fills and road embankments (Bosscher et al. 1992; Hossain et al. 1995, Fedroff et al. 1996, Zhu and Carlson 1999, Pierce and Blackwell 2002, Frantzis 2003, Nehdi et al. 2005).

One of the mature and primary uses of tire rubber is incorporating crumb rubber for modifying asphalt binders in asphalt pavements (Hossain et al. 1995, Navarro et al. 2005). This included the use of tire rubber in pavement crack and joint sealants; binders for chip seals, inter-layers, and hot-mix asphalts; and membranes (Amirkhanian 2001). Similar to conventional asphalt concrete, tire rubber modified hot asphalt mixes are widely influenced by thermal changes (McGennis 1995). Very successful applications of scrap tires in hot mix asphalt were reported in many states in the US including Maryland and South Carolina (Amirkhanian 2001). Experiments and field observations showed that the use of tire rubber particles in hot mix asphalt can enhance the resistance to thermal cracking, rutting, reflective cracking, ageing, and chip retention (Heitzman 1992 and Shuler et al. 1985).

While these fields of applications provided successful areas for recycling tire rubber, this total consumption of scrap tires with respect to the current volumes of scrap tires is still considerably small. It has become obvious that unless tire rubber can be recycled in a systematic way in applications with large production volumes, the suggested methods will have limited effect in helping to reduce the practice of stockpiling scrap tires. The use of ground tire rubber in a variety of rubber products and thermal incineration of waste tires for the production of heat and electricity have also