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ScienceDirect

Procedia Engineering 210 (2017) 472–478

Procedia Engineering

www.elsevier.com/locate/procedia

6th International Workshop on Performance, Protection & Strengthening of Structures under Extreme Loading, PROTECT2017, 11-12 December 2017, Guangzhou (Canton), China

# Fire Protection of Concrete Tunnel Linings with Waste Tyre Fibres

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**Abstract**

The damages caused by fire-induced explosive spalling of concrete in tunnels can be tremendous; it could result in enormous economic cost and potential loss of human life. For this reason, the structural fire protection of concrete tunnel linings plays an important role in the tunnel design. Polypropylene fibres have been used in concrete to prevent explosive spalling of concrete exposed to fire. On the other hands, thousands of tonnes of polymer fibres are generated worldwide as a by-product of the recycling of end-of-life tyres. Storage of these fibres is a problem, since it is flammable, of low density (and so very large in volume) and can be carried away by wind and pollutes the surrounding environment. They are also too agglomerated or contaminated with rubber to find any alternative use, and are generally disposed of by incineration. The polymer fibre recycled from tyres has equal high quality and durability as manufactured fibres. Finding ways of introducing these fibres in concrete can potentially reduce the use of virgin fibres and delivery a more environmental-friendly spalling-mitigation solution. This paper shows the preliminary outcomes of this research, which indicates the potential of using these recycled fibres to prevent fire spalling instead of manufactured polypropylene.


Peer-review under responsibility of the scientific committee of the 6th International Workshop on Performance, Protection & Strengthening of Structures under Extreme Loading.

*Keywords:* Concrete, Spalling; Fire; Tyre; Waste; Polymer Fibre, Tunnel.

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1877-7058 
Peer-review under responsibility of the scientific committee of the 6th International Workshop on Performance, Protection & Strengthening of Structures under Extreme Loading.
10.1016/j.proeng.2017.11.103

## 1. Introduction

Fire-induced spalling in tunnels can cause extensive damage and costly repair costs, it could also potentially result in significant loss of human life. High performance concrete, increasingly used in tunnel linings, is more vulnerable to fire spalling, mainly due to its reduced permeability and porosity [1]. The fire-induced explosive spalling can sometime cause significant loss of cross section of tunnel linings and expose the embedded reinforcement steel, which could jeopardize the structural integrity of the tunnel [2] and may induce flooding risks in the case of underwater tunnels. For this reason, the structural fire protection of concrete tunnel linings plays an important role in the tunnel design.

Polypropylene fibres (PPF) have been used in concrete to prevent explosive spalling of concrete exposed to fire [3-8]. The idea is that PPF melts at ≈170 ºC and completely disintegrated at ≈340ºC, hence, can create voids which are thought to release vapour pressure; they enhance the permeability of concrete at high temperatures, especially at temperatures close to the melting point [1]. Its effectiveness in the mitigation of fire spalling also depends of several factors such as fibre dosage, type, diameter, length, etc.

An estimated one billion tyres [9] are produced each year and a similar (but slightly lower) number runs out their service life. Since 2006, EU Landfill Directive has prohibited the disposal of whole tyres and tyre by-products to landfill. The Waste Incineration directives also set environmental controls to reduce the use of tyres for energy recovery. Tyre rubber crumb for example, a blend of natural and synthetic rubbers, carbon blacks and chemical admixtures, has a well-established market. Tyre rubber is vulcanised and it cannot be reformed directly into new rubber products, but has applications as a filler or as a soft surface for playgrounds, artificial sports surfaces, sound insulation and equestrian applications. Another tyre by-product, steel fibres, is also readily recovered in a fairly contaminated state (about 10% rubber and textile), which is usually sent for re-melting. If cleaned further to reduce rubber contamination below 1% and screened to remove ineffective fibre lengths, this Recycled Tyre Steel Fibres (RTSF) can be used as fibre reinforcement for concrete. Another major by-product of end-of-life tyre recycling is the polymer fibre. The storage of these fibres is a problem, since the material is flammable and is easily carried away by wind. These fibres are often too agglomerated and contaminated with rubber to find any alternative use, and are generally disposed of by incineration, recovering only 25% of the energy used to produce these fibres. On the other hand, up to 75k tonnes/annum of PPF are estimated to go into concrete in Europe alone and an estimated 63k tonnes/annum of polymer fibres (nylon, rayon, aramid, etc.) are derived as a by-product of the recycling of end-of-life tyres. The polymer fibre recycled from tyres has equal high quality and durability as manufactured fibres. Finding ways of introducing these fibres in concrete can potentially reduce the use of virgin fibres and delivery a more environmental-friendly spalling-mitigation solution.

The on-going research aims to develop an improved understanding of explosive spalling of modern high-performance concrete, and to find a sustainable spalling-mitigation solution by using Recycled Tyre Polymer Fibres (RTPF) recovered from end-of-life tyres. This paper presents the preliminary outcomes of this research, showing the effectiveness of these recycled fibres on the prevention of fire spalling.

## 2. Recycled tyre polymer fibre

### *2.1. Cleaning and geometrical characterization*

Type polymer fibres are extracted from mechanical shredding of end-of-life tyres, Fig. 1a. The waste fibres supplied by the tyre recyclers are heavily contaminated with over 30% (by weight) of rubber fine dusts or larger partials, which can affect concrete properties significantly. Therefore, intensive cleaning is required before these waste fibres can be used in concrete. The cleaned fibre, called Recycle Tyre Polymer Fibre, is shown Fig. 1b. Techniques for removing rubber contamination and separating tangled filaments for the large-scale production of RTPF for use in concrete did not exist. A prototype device for removing rubber dusts and particles from the tyre polymer fibres has been developed in this research. The device is based on an airflow method, which was proved efficient in processing contaminated tyre polymer into RTPF.