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Review

Composites with recycled rubber aggregates: Properties and opportunities in construction

Nelson Flores Medina [a,*], Reyes Garcia [b], Iman Hajirasouliha [b], Kypros Pilakoutas [b], Maurizio Guadagnini [b], Samar Raffoul [b]

[a] Departamento de Construcción y Tecnología Arquitectónicas, E.T.S. Arquitectura, Universidad Politécnica de Madrid, Avda. Juan de Herrera 4, 28040 Madrid, Spain
[b] Dept. of Civil and Structural Engineering, The University of Sheffield, Sir Frederick Mappin Building, Mappin Street, Sheffield S1 3JD, UK

HIGHLIGHTS

- The possibilities of recycled rubber composites used in construction are studied.
- The mechanical and physical properties of rubber have been summarized.
- Rubber manufacture and recycling methods have been presented.
- The drawbacks resulting from the incorporation of rubber in composites are addressed.

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ABSTRACT

Vulcanised rubber is extensively used in many industrial sectors due to its good physical, mechanical and dynamic properties, as well as excellent durability, outstanding abrasive resistance and relatively low cost. Unfortunately, most post-consumer rubber-derived products are still discarded as waste, buried in landfills or incinerated. Such materials require many years to degrade naturally due to i) their complex cross-linked composition, and ii) the additives used during manufacturing to extend the lifespan of rubber. Extensive research has investigated the use of end-of-life rubber as binder (e.g. elastomers, bitumen), or as conglomerates (cement, gypsums) to produce innovative composites in construction. To improve the properties of composites made with recycled rubber, the surface of rubber has been treated with different costly processes to improve the Interfacial Transition Zone (ITZ). However, the results available in the literature are inconsistent and many technical and practical aspects remain unsolved, thus preventing the cost-effective use of rubber in the construction industry. This study provides a comprehensive review on rubber properties and surface treatments of rubber recycled from post-consumer components so as to identify potential applications in composites for construction. It is concluded that an understanding of the chemical, physical and mechanical properties of rubber, as well as a proper characterisation, are necessary to take full advantage of this high quality material. Future research needs in the field are also suggested.

Contents

* Corresponding author.
E-mail address: nelson@arquingenieros.com (N.F. Medina).

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1. Introduction

Rubber (cured rubber compound or vulcanised rubber) has been used in various industrial applications since the Industrial Revolution. In particular, the development of the vulcanisation process [45] allowed the cost-effective production of large volumes of high-quality rubber. Current global rubber production is approximately 26.7 M tons, of which 12.31 M are natural and 14.46 M synthetic rubber to produce tyres and other industrial and consumer products [116]. Global tyre production is estimated at 1.5Bn units/year, and approximately the same number of tyres reach their service life every year [32]. End-of-life tyres contain up to 90% of vulcanised rubber which cannot be easily recycled due to the complex cross-linked structure achieved through vulcanisation [1]. The inappropriate disposal of rubber from these tyres is hazardous to the environment [153] and, consequently, stringent EU directives prioritise the reuse and recycling of rubber and ban tyre landfilling (Directive, 2008/98/EC and Landfill Directive 1991/31/EC, respectively). This has increased the efforts towards generating novel applications for all end-of-life tyre components in various industrial sectors.

Vulcanised rubber is extremely durable, strong, flexible and can maintain its volume under loading, thus making it suitable to be used as aggregate for composites. However, to date most of the rubber recovered from tyres is burnt as fuel, a process which produces hazardous gases and only recovers 25% of the energy used to produce rubber [33]. More environmentally friendly processes have been developed to recover rubber, such as tribo-electric separation, froth flotation method or laser-induced breakdown spectroscopy [1,129,35]. However, these are still expensive, and the recovered rubber varies considerably in cleanliness, size, shape and quality of surface finish. Recovery methods affect the suitability of recycled rubber for use in the manufacture of new composite products. For instance, small rubber granulates have more contact surface than large rubber chips, and therefore the former adhere better to a matrix [53,132,37,38]. However, the associated costs of obtaining small rubber sizes also increase [71].

Over the last decades, extensive research has investigated the use of recovered rubber in composites [1] and particularly in the construction industry, which is the main consumer of raw materials worldwide. The use of recovered rubber from tyres in concrete as a replacement of portions of the concrete mineral aggregates has also been considered [88,155]. However, the addition of rubber reduces the workability and strength of concrete, and increases its micros-cracking and lateral expansion under compressive load. Consequently, the use of rubberised concrete in high-value structural concrete applications is very limited to date. Recent research by Raffoul [105] identified a lack of consensus on how to quantify the influence of rubber on the physical and mechanical properties of fresh and hardened concrete. The insufficient understanding of the chemical and mechanical behaviour of rubber, combined with its adverse effect on some concrete properties has limited its widespread use in the construction industry. Moreover, the composition and fundamental behaviour of the different types of rubbers need to be understood to fully exploit their properties in high-value applications in construction.

This article examines critically the current challenges and future potential applications of rubber in composites for construction, including composites with different binders and conglomerates. Based on a comprehensive literature review, Section 2 reviews the properties of different types of rubbers, their manufacturing and recycling processes, and discusses the feasibility of rubber characterisation before recovering/recycling. As the mechanical properties of rubberised composite depend heavily on the bond between aggregates and matrix at the Interfacial Transition Zone (ITZ), the different techniques used to treat the surface of rubbers (and other polymers) are critically revised in Section 3. Section 4 summarises the typical properties of composites used in the construction industry, with emphasis on the amount of recovered rubber and mix designs investigated in the literature. Finally, Section 5 gives new directions on potential high-value applications of rubber in construction, as well as recommendations for future research.

2. Composition and properties of rubber

The properties of rubber compounds depend directly on its microstructure, which is generally formed by elastomeric chains (also named as natural rubber, polymer or resin) and fillers/additions that in turn form a continuous and homogeneous polymeric composite. There are two main types of plastic products: thermoplastics and thermosettings [46] (Nakajima, 1993). Thermoplastics are polymers composed by monomers organised in independent large chains that change their properties with an increase in temperature without an associated phase change. The degree of polymerization DP (or molecular weight) of a rubber is determined by the number of monomeric units in a macromolecule. Higher density and mechanical strength of a thermoplastic correspond to higher values of DP. Whilst chemical covalent forces bond strongly a single chain, different chains are bonded with secondary (weak) 'Van der Walls' forces. The 3D zigzag molecular architecture of these chains has freely rotating bonds, which enable the rubber molecule to stretch and shorten without any change in its internal