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Investigating the feasibility of a reuse scenario for textile fibres recovered from end-of-life tyres

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ABSTRACT

The management of end-of-life tyres (ELTs) is regulated by several national and international legislations aiming to promote the recovery of materials and energy from this waste. The three main materials used in tyres are considered: rubber (main product), which is currently reused in other closed-loop applications; steel, which is used for the production of virgin materials; and textile fibres (approximately 10% by weight of ELTs), which are mainly incinerated for energy recovery (open-loop scenario).

This study aims to propose and validate a new closed-loop scenario for textile fibres based on material reuse for bituminous conglomerates. The final objective is to verify the technical, environmental, financial, and economic feasibility of the proposed treatment process and reuse scenario. After characterization of the textile material, which is required to determine the technological feasibility, a specific process has been developed to clean, compact, and prepare the fibres for subsequent reuse. A life cycle assessment (LCA) has been carried out to quantify the environmental benefits of reusing the fibres. Finally, a cost benefit analysis based on the LCA results was conducted to establish the long-term financial and economic sustainability.

From a technological point of view, the tyre textile fibres could be a promising substitute to the reinforcement cellulose commonly used in asphalts as long as the fibres are properly prepared (compaction and pellet production) for application in the standard bituminous conglomerate production process. From an environmental point of view, relevant benefits in terms of global warming potential and acidification potential reduction were observed in comparison with the standard incineration for energy recovery (respectively −86% and −45%). Moreover, the proposed scenario can be considered as financially viable in the medium to long term (cumulative generated cash flow is positive after the 5th year) and economically sustainable (expected net present value of more than €3,000,000 and economic rate of return of approximately 30%). Finally, the sensitivity and risk analyses show that no specific issues are foreseen for the future implementation in real industrial applications.

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1. Introduction

Waste and waste management are primary issues that modern society has to address in order to ensure a liveable Earth for future generations (Hanifzadeh et al., 2017). The European Union (EU) drafted several plans to favour the transition towards a resource-efficient economy where wastes become resources to exploit instead of problems to manage (European Parliament and Council, 2013; European Commission, 2015).

End-of-life vehicles (ELVs) and end-of-life tyres (ELTs) represent a relevant percentage of solid wastes and thus are a priority in the EU waste legislation framework which includes specific directives for this sector (European Parliament and Council (2000)). European and national legislations are clearly inspired by the extended producer responsibility concept which identifies producers (and importers) as polluters, involving them in the responsibility of waste management of products they produce and commercialize (European Commission - DG Environment, 2014). For instance, in Italy, ELT dismantling is managed by different consortiums created by tyre producers operating nationwide and by several authorized recycling companies as regulated by the specific legal framework (DL 2006; DM 2011; DM 2012).

According to the European Tyre and Rubber Manufacturers Association (ETRMA) statistics in 2013, the quantity of used tyres in EU was approximately 3.6 million tonnes, mostly collected in Germany, United Kingdom, France and Italy. Figures highlight that the EU directives are effective, because most of the collected ELTs

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are correctly managed and dismantled. Only 2% of the residual wastes produced in EU28 are landfilled (4% including Norway, Switzerland, and Turkey) and most of the EU countries (e.g. Germany, Spain, and Italy) reached the 100% recovery of ELTs in 2013. However, the quickest route for recovered tyres is certainly their use for energy recovery. From 32% registered in 1994, the percentage of ELTs used for material recovery is slowly increasing but in recent years there is only a 50/50 mix that can be observed (EASME, 2015; ETRMA, 2015). This means that a large fraction of materials coming from the ELT treatment are used in open-loop scenarios which do not constitute the best option according to the environmental hierarchy (Favi et al., 2017).

The ELT treatment process essentially consists of ambient or cryogenic grinding and primarily aims at recovering triturated rubber in various sizes and types which represents the main portion of ELT materials (WBCSD, 2010). The separation of different compounds (mainly rubber and elastomers) is a very difficult or impossible task (ERTMA, 2015); thus, the granulated or pulverized rubber fraction is used for the production of other products/materials such as plastic compounds, concrete, asphalts, rails, or athletics tracks (Fornai et al., 2016). Generally, the incorporation of rubber leads to a positive effect in terms of weight, mechanical performance, durability, noise, and environmental sustainability (Aliapur, 2010; Ramarad et al., 2015; Aoudia et al., 2017; Nazzal et al., 2017).

During the treatment of tyres, two other sub-products are generated in substantial quantities which are namely steel and textile fibre (Pacheco-Torgal et al., 2012; Ecopneus, 2013). According to the ERTMA report, steel recovered from ELTs is generally a high-quality material with a large demand by the steel industry where it is used for the production of new virgin steel. However, textile fibres represent a challenge for ELT recycling companies, because they strongly contribute to the generation of dust in the working environment, which can result in health problems for operators (ETRMA, 2015). In addition, textile fibres are classified as special wastes (European Waste Catalogue – EWC code 19.12.08) to be disposed or incinerated.

After the tyre grinding process, the output fibres are contaminated with rubber (Re Depaolini et al., 2017) and have several unfavourable characteristics: (i) they take the form of soft bundles that cannot be uniformly mixed with other materials, such as plastic compounds or bituminous conglomerates; (ii) they accumulate electrostatic charges within the bundles, which limit the possibility of extruding them in combination with a compound; and (iii) they have a high volume and a low specific weight (approximately 140 kg/m^3) which makes the transportation very expensive. However, studies have investigated the use of waste tyre fibres for different applications in particular for reinforced cement (Flores Medina et al., 2017; Sofi, 2017; Sousa et al., 2017). Li et al. (2004) evaluated the influence of waste tyre fibres on the strength and stiffness of concrete. Yadaw and Tiwari (2017) proved the applicability of waste rubber fibres as fill materials in cement stabilized clays. Van de Lindt et al. (2008) applied scrap tyre fibres in building insulation panels to increase efficiency. Landi et al. (2016) provided a comparison between different second life applications of fibrous materials in terms of environmental benefits and waste disposal reduction.

The current study aims to integrate the above-mentioned studies by proposing and evaluating the economic and environmental feasibility of an alternative tyre textile fibre end-of-life scenario. Through the development of a specific treatment process, the textile materials can be reused for the preparation of reinforced bituminous conglomerates with improved mechanical performances in comparison with the standard ones. Even if this is one of the most common applications for the ELT rubber fraction (Sienkiewicz et al., 2017), reuse of ELT fibres in this sector has never been thoroughly investigated. The final objective is to quantitatively demonstrate that the new reuse scenario based on fibre cleaning could lead to economic revenues as well as environmental benefits. As a consequence, the ELT recycling chain will be improved, as a larger fraction of recovered materials could potentially have a closed-loop scenario, according to circular economy principles. In addition, a longer lifetime of asphalts realized by using tyre textile fibres is expected (Gonzalez et al., 2012; Liang et al., 2015) which will lead to cost reduction in road rehabilitation and maintenance (Blessen et al., 2016).

The paper is organized as follows. Section 2 describes the textile material characterization and the technical issues related to its application in bituminous conglomerates. Section 3 provides a detailed description of all the required processes for fibre cleaning, preparation, and reuse. Section 4 presents the life cycle assessment (LCA) study which is carried out to verify the environmental sustainability of the proposed scenario. Section 5 presents the cost–benefit analysis (CBA) conducted to establish the financial and economic feasibility. Section 6 discusses the obtained results and presents sensitivity and risk analyses which complete the feasibility study. Finally, Section 7 reports the conclusions and related future work.

2. Textile material characterization and valorisation

The technical and sustainable feasibility evaluation of the second life application firstly requires to define how to use the waste material as a subsequent raw material.

2.1. Textile material characterization

Tyres are made up of four main parts: (i) tread, which is designed for contact with the ground and to ensure proper friction; (ii) carcass, which is the structural part of the tyre on which the tread is vulcanized; (iii) shoulder, which minimizes the effects of irregularities of the terrain and transfers the load due to braking and oversteering under acceleration; and (iv) heels, which is used to fit the casing to the rim. Regarding the constituent materials, tyres have mixed compositions of carbon black, elastomer compounds, steel cord, and fibres, in addition to several other organic and inorganic components. Each material contributes to the particular characteristics of a tyre which promote longer life and attain a specific level of friction (Wei et al., 2005; Yang and He, 2013; Torretta et al., 2015). Table 1 presents a brief overview of this composition (ETRMA, 2015).

The following sub-sections describe the tests carried out on the textile material to establish its composition and the most important characteristics. Each test was repeated on 5 different lots of textile materials in order to ensure statistical significance.

2.1.1. Apparent density and thermal conductivity

Apparent (or bulk) density is defined as the ratio between mass and the volume occupied. This volume occupied by the fibres includes the space between the solid parts in addition to the one occupied by them. Apparent density is often used in the study of powders or fibres, which are generally formed by a mixture of air and solid particles. In order to obtain a repeatable and comparable measurement with various tests, the density measurement was associated with the measurement of the thermal properties of the fibre such as thermal conductivity, specific heat, and diffusivity. These parameters are influenced by the density of the material being analysed.

In this study, the thermal properties were measured using the ISOMET 2104 system equipped with a 'needle probe'. Five series of thermal measurements were carried out at three different density values (Table 2).

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