USED TIRE MANAGEMENT: AN OVERVIEW, PART I

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Abstract: *Worldwide, approximately 19.3 million tonnes of used tires are generated every year. Used tires represent a category of waste whose processing is especially difficult because of their complex structure and varied composition. Improper management of used tires endangers environment and social life. Therefore, the used tires management is a matter of a country's attitude towards supporting the environment preservation and it is emerged as a novel area of scientific research. This paper is the first part of the review paper, which investigates the used tires management research area. However, in this particular paper, due to enacted limit in paper's length, only previous review papers, legislation-oriented research and application alternatives are addressed and systematically analyzed. The purpose of this review paper is to provide an extensive content analysis overview of exclusively peer-reviewed international journal papers published in the period 2006-2017.*

Keywords*: review, content analysis, used tires, legislation, application alternatives.*

1. INTRODUCTION

In the last few decades, the treatment of used tires is becoming more intensive and important (Oikonomou and Mavridou, 2009; Li et al., 2016). There are approximately 19.3 million tonnes of used tires generated annually in the world (Labaki and Jeguirim, 2017), and this figure is going to rise in the coming years along with the expected growth of the world's motor vehicle fleet. In the European Union (EU), the quantity of used tires reached over 3.6 million tonnes in 2013 (ETRMA, 2016). Since used tires are not biodegradable, there is a strong motivation to successfully manage this fast-growing waste flow thus mitigating its negative environmental impact.

Due to the increasing importance of the used tires management subject, a considerable number of research papers have been published. Grey literature is completely excluded from this review paper. Its primary purpose is to categorize, analyze and interpret exclusively peer-reviewed international journal papers published in the period 2006-2017.

2. REVIEW METHODOLOGY

In this paper, content analysis method is adopted for literature review. Content analysis is an observational research method that is used to systematically evaluate the symbolic content of all forms of recorded communication and also helps to identify the literature in terms of various categories (Pokharel and Mutha, 2009).

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Search engines were used to explore ACS Publications, ASCE Library, ASME Digital Library, Cambridge JOURNALS, EBSCOhost, EmeraldInsight, Google Scholar, IEEE Xplore, Inderscience, IntegraConnect, IOPScience, J-STAGE, JSTOR, ProQuest, RSCPublishing, SAGE journals, ScienceDirect, SciVerse, SpringerLink, and WILEY databases for literature. In addition, the references cited in each relevant literature were examined to find out additional sources of information.

3. RESULTS

Recently, several review papers have been published. Sienkiewicz et al. (2012) described different organizational approaches for the management of used tires in the European Union and some possible usages of waste tires as a source of raw materials or alternative fuel. Williams (2013) as well as Martínez et al. (2013) reviewed applications of pyrolysis for waste tires treatment. Ambalal and Dipak (2014) provided a review of applications of the Life cycle analysis (LCA) methodology for solving used tires management problems and highlighted some future research directions. Ramarad et al. (2015) provided an overview of the progress in waste tire recycling with a particular attention to incorporation of waste tire rubber into polymeric matrices. Saleh and Gupta (2016) discussed the methods developed for the preparation of carbon from waste tires and their activation.

As can be seen from contents analysis of previously published review papers, the scope of every paper is limited to a specific area of the used tires management. In this paper, we present a holistic view of environmental engineering issues of the used tires management by covering a wide range of previously published papers. The literature is organized into 4 main sub-areas: legislation-oriented research, treatment options, mathematical modeling approach and application alternatives.

3.1 Legislation-oriented research

European tire producers face an array of extended producer responsibility (EPR) legislations, which make them responsible for financing and organizing the take-back, treatment and recycling of used tires. The legislation on the used tires management has evolved considerably over the years, but there is still much space for improvement.

Regarding the legislation applied on used tires management in the EU, there are three different systems: (a) producer responsibility, (b) tax system, and (c) free market system. McKerlie et al. (2006) outlined lessons from European and Canadian used tires stewardship programs thus highlighting the importance of designing specified extended producer responsibility (EPR) programs. They also provided some recommendations for advancing EPR in Canada. Mayers (2007) analyzed strategic, financial and design implications of EPR principle on waste batteries, end-of-life vehicles and used tires. Since the Portuguese government decided to apply EPR concept to the used tires management, Ferrao et al. (2008) identified producers, distributors, recyclers and retreaders, as well as analyzed present processing infrastructures in Portugal. Uruburu et al. (2008) highlighted that new policies and EPR principle strongly affect overall environmental performances of tires throughout their life cycle. As a good example of an environmentally-sound practice with used tires, the authors mentioned SIGNUS, the Spanish non-profit organization. Milanez and Bührs (2009) concluded that an in-depth study of the scope, main new aspects, objectives and future targets of the used tires management needs to be conducted to provide an updated, more precise and clearer framework.

Santini et al. (2011) found that removal of used tires from end-of-life vehicles is needed in order to fulfill rigorous recycling and recovery targets promulgated by the Directive 2000/53/EC. Antoniou and Zabaniotou (2013) outlined that a general guideline for EU member states is to reach a zero post-consumer amount of tire disposal in landfills, and to accomplish a balance

between economy and environmental protection. Torretta et al. (2015) compared treatment and disposal schemes with used tires in Italy and Romania.

New ISO 10844 test track specification further brings attention to tire noise behavior. For instance, works of Sohaney et al. (2012) and Wei et al. (2016) provide analyses of noise of heavy truck tires and the new ISO specifications. Clar-Garcia et al. (2016) studied the European regulations devoted to reduction of noise generated by the interaction of tires and road surface.

The recent regulations, such as the European tire labeling regulation EC/1222/2009, are devoted to put in focus environmental and safety performances of tires. Elenour and Laz (2014) explored the ideal way of tire exploitation to guarantee maximum safety and life time. Xie et al. (2016) concluded that tire manufacturers are taking measures to modify the structure of tires in order to avoid uneven wear.

3.2 Application alternatives

Environmental concerns and ever-growing quantity of used tires have stimulated the search for novel application alternatives. More and more countries worldwide have been paying great attention to the comprehensive utilization of used tires to protect environment, reduce consumption of natural resources and save energy.

Many researchers have investigated end-of-life tires application alternatives. For instance, Tlemat et al. (2006) demonstrated that steel fibres recovered from end-of-life tires can be successfully used to prepare fibre-reinforced concrete. Lee and Roh (2007) proposed application of recycled tire chips on the culvert walls in backfill areas to reduce the dynamic earth pressure induced by the compaction loading as well as to improve the characteristics of compacted soils. Oikonomou and Mavridou (2009) examined the incorporation of tire rubber granules as a partial replacement for the sand in cement mortars. Fiksel et al. (2011) investigated usage of end-of-life tires in civil engineering applications and concluded that it is environmentally preferable alternative.

End-of-life tires can be used in a variety of civil and non-civil engineering applications. Major application options are numerous and usually include:

- artificial reefs (Chapman and Clynick, 2012),
- dock fenders (Feriha et al., 2014),
- draining material (Pérez et al., 2012; Vila et al., 2012; Torreta et al., 2015),
- embankment stabilizers (Lindt et al., 2008; Li et al., 2016; Rowhani and Rainey, 2016),
- erosion barriers (Edinçliler et al., 2010),
- flooring sports fields (Bravo and Brito, 2012),
- footwear industry (Machin et al., 2017),
- foundation for roads and railways (Chiu, 2008; Sengul, 2016),
- gardening (Fıglali et al., 2015),
- mats (Machin et al., 2017),
- packing material (Karaağaç et al., 2017),
- paving blocks (Ling, 2012; Zhou et al., 2014; Said et al., 2015; Zanetti et al., 2015),

- roofing materials (Torreta et al., 2015; Karaağaç et al., 2017).

4. CONCLUSION

The used tires management strongly affects not only the environmental protection but also the resources preservation, since problems related to the depletion of resources, energy demand and waste management are interconnected thus requiring an integrated approach.

This paper is the first part of the review paper, which investigates the used tires management research area. It presents a holistic review of the state-of-the-art literature published in the period 2006-2017 exclusively in peer-reviewed international journals. In this part, due to enacted limit in paper's length, only previous review papers, legislation-oriented research and application alternatives are addressed and systematically analyzed.

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