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Alternatives for End-of-Life Tire Disposal

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Alternativas de destinação para pneus inservíveis

RESUMO
A presente pesquisa aborda a temática da destinação adequada de pneus inservíveis, sendo estes pneus compostos por borrachas, negro de fumo, têxteis e aço. A problemática dos pneus inservíveis está diretamente relacionada a sua não-biodegradabilidade, sendo este, um resíduo que leva até seis séculos para se decompor. Diversos problemas ambientais, de saúde pública e econômicos são consequência do acúmulo inadequado deste resíduo. Sendo assim esta pesquisa tem como foco uma revisão bibliográfica sistemática que visa identificar as diversas maneiras de destinações ambientalmente adequadas para pneus inservíveis no Brasil e no mundo, sendo elas divididas em reutilização, reaproveitamento e reciclagem Também foi pesquisado como é realizada a coleta destes pneus inservíveis no Brasil, a fim de entender quais as maiores dificuldades encontradas para levar este resíduo até locais onde este possa encontrar uma destinação adequada. Os pneus inservíveis têm potencial de se transformarem em matéria prima para confecção de artesanatos, incorporação em materiais de construção civil e até de serem utilizados como fonte alternativa de combustível na indústria cimenteira. Desta forma, a destinação adequada de pneus inservíveis é crucial para preservar recursos naturais e reduzir o acúmulo de resíduos evitando danos ambientais e a saúde pública. Na maioria dos casos os pneus inservíveis são reutilizados ou reciclados e na minoria dos casos reaproveitados.

PALAVRAS-CHAVE: Reciclagem. Reaproveitamento. Reutilização.

Alternatives for End-of-Life Tire Disposal

ABSTRACT
This research addresses the topic of proper disposal of end-of-life tires, which are composed of rubber, carbon black, textiles, and steel. The problem with end-of-life tires is directly linked to their non-biodegradability, as these residues can take up to six centuries to decompose. Numerous environmental, public health, and economic issues arise from the improper accumulation of this waste. Therefore, this study focuses on a systematic literature review aimed at identifying various environmentally appropriate disposal methods for end-of-life tires in Brazil and worldwide, categorizing them into reuse, recovery, and recycling. It also examines how end-of-life tires are collected in Brazil to understand the main challenges in transporting this waste to facilities capable of proper disposal. End-of-life tires have the potential to be transformed into raw materials for crafting, incorporated into construction materials, or even used as an alternative fuel source in the cement industry. Thus, the proper disposal of end-of-life tires is crucial for preserving natural resources and reducing waste accumulation, preventing environmental damage and harm to public health. In most cases, end-of-life tires are reused or recycled, and in fewer cases, recovered.

KEYWORDS: Recycling, Recovery, Reuse.

Alternativas para la disposición de neumáticos fuera de uso

RESUMEN
La presente investigación aborda la temática de la disposición adecuada de los neumáticos fuera de uso, los cuales están compuestos por caucho, negro de humo, textiles y acero. La problemática de estos neumáticos está directamente relacionada con su no biodegradabilidad, siendo un residuo que puede tardar hasta seis siglos en descomponerse. Diversos problemas ambientales, de salud pública y económicos son consecuencia del acúmulo inadecuado de este residuo. Por lo tanto, esta investigación se centra en una revisión bibliográfica sistemática para identificar las diversas maneras de disposiciones ambientalmente adecuadas para los neumáticos fuera de uso en Brasil y en el mundo, clasificándolas en reutilización, reaprovechamiento y reciclaje. También se investigó cómo se realiza la recolección de estos neumáticos en Brasil, con el objetivo de comprender las principales dificultades para llevar este residuo a lugares donde pueda recibir una disposición adecuada. Los neumáticos fuera de uso tienen el potencial de transformarse en materia prima para la confección de artesanías, la incorporación en materiales de construcción civil e incluso ser utilizados como fuente alternativa de combustible en la industria cementera. De esta manera, la disposición adecuada de los neumáticos fuera de uso es crucial para preservar los recursos naturales y reducir el acúmulo de residuos, evitando daños ambientales y a la salud pública. En la mayoría de los casos, los neumáticos fuera de uso se reutilizan o reciclan y, en menor proporción, se reaprovechan.

PALABRAS CLAVE: Reciclaje, Reaprovechamiento, Reutilización.

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1 INTRODUCTION

In accordance with the Brazilian National Environmental Council (CONAMA, *Conselho Nacional do Meio Ambiente*) Resolution 416 of September 30, 2009, which provides for the prevention of environmental degradation caused by unserviceable tires and their environmentally appropriate disposal, unserviceable tires are: “used tires that present irreparable damage to their structure and are no longer suitable for running or reform” (BRAZIL, 2009). In general, unserviceable tires come from motorcycles, cars and trucks.

According to the Brazilian National Association of the Tire Industry (ANIP, *Associação Nacional da Indústria de Pneumáticos*), the tire is manufactured by various components, responsible for the performance necessary to guarantee all the characteristics required by this complex product. The proportion of items in tire composition varies, depending on the required load capacity, speed of use and, mainly, each type of vehicle and application. In passenger car tires, which run on paved roads, synthetic rubber is used more often than natural rubber. In cargo truck tires, used on multiple roads, the use of natural rubber prevails, due to its greater resistance to cuts and lacerations (ANIP, 2023).

Tires are made up of different materials, which basically include rubbers, which are called elastomers with concentrations ranging from 45 to 47%. In addition to rubbers, there is carbon black (21.5 to 22%), the textile that accounts for approximately 11% of the structure that makes up the tire and metal or wires that act as structural reinforcement (12 to 25%), which accounts for around 8 kg of the weight that constitutes a vehicle tire considered light (BUSS, 2021).

Unserviceable tires are one of the fastest growing solid wastes due to population growth, leading to rapid growth in the automotive industry, being a global problem (CHEN *et al.*, 2022).

The greatest problem when it comes to solid waste from unserviceable tires is that these are non-biodegradable materials (taking 600 years to decompose), and, if not disposed of properly, can generate several environmental, socioeconomic and human health problems. The accumulation of these tires generally occurs in open places and exposed to the effects of bad weather, including rain, which generates an accumulation of water inside the tires, thus creating an environment conducive to the proliferation of mosquitoes, consequently proliferating diseases. In this regard, the incorrect disposal of tires also has an impact on human health (SAUD, AHMED, MONCEF, 2020; KHERN *et al.*, 2020). Tires left in open environments contaminate soil and water, as they leach chemical substances and burning them poses a risk to the environment and human health (BUSS, 2021).

Since it is non-biodegradable waste and the fact that almost a billion tires accumulate every year in the world, the need to find alternatives for disposing of this material is evident (SAUD; AHMED; MONCEF; 2020).

Concerned about potential environmental health problems and risks of fires in storage areas for unserviceable tires, the Taiwanese government began encouraging and regulating unserviceable tire recycling in 1980, showing the rest of the world how regulatory and subsidiary policies can have significant impacts in this aspect (WEN *et al*., 2016).

Many items become waste when they reach the end of their life or when their duties are no longer relevant or priority, and can have many origins, but everything is directed towards a single classification, with each country having its own particularities according to its own legislation. The European Tyre & Rubber Manufacturers Association (ETRMA) and the European Union are the precursors of all standards and decisions regarding relevant legislation regarding the final disposal of unserviceable tires in Europe. In Brazil, there is a combination of laws and regulations that describe everything from tire production to final disposal, with a description of the responsibilities of each author in the process that involves tires. Brazil also follows deliberations by ETRMA and the European Union, Ecopneus from Italy and Signus from Spain (BUSS, 2021). The NBR 10.004 standard, November 30, 2004, of the Brazilian Association of Technical Standards (ABNT, *Associação Brasileira de Normas Técnicas*), classifies unserviceable tires in Class II - non-hazardous (BRAZIL, 2010).

Law 12,305, August 2, 2010, establishes the Brazilian National Solid Waste Policy (PNRS, *Política Nacional de Resíduos Sólidos*), and determines the responsibilities of generators for the product's life cycle, in which waste disposal includes reuse, recycling, composting, energy recovery and use or other destinations in order to avoid damage or risks to public health and safety and minimize adverse environmental impacts (BRAZIL, 2010).

The Brazilian National Program for Unserviceable Tire Collection and Disposal (RECICLANIP, *Programa Nacional de Coleta e Destinação de Pneus Inservíveis*), implemented by ANIP, is responsible for all management of the logistics of removing unserviceable tires from collection points in Brazil and for environmentally appropriate disposal in companies licensed by the competent environmental bodies and approved by the Brazilian Institute of the Environment and Natural and Renewable Resources (IBAMA, *Instituto Brasileiro do Meio Ambiente e de Recurso Naturais e Renováveis*) in more than 1,400 municipalities, with a geographical coverage greater than the 326 municipalities with more than 100 thousand inhabitants required by CONAMA Resolution 416/2009 (BRAZIL, 2009).

Hence, we can see a scenario in which end-of-life tire management, as part of an environmental policy, enables new means and/or recycling methods to contribute to reducing the global rate of non-recycled material in a way that reduces the environmental and public health problems generated by this waste. Unserviceable tires should be considered a source of valuable materials and structures that can be used to produce new goods and products (BUSS, 2021).

Therefore, the present research aimed to carry out a systematic bibliographical review with the main aim of obtaining information in studies from the last decade regarding the forms of reuse, reprocess and recycling of this waste.

2 MATERIAL AND METHODS

Based on the aforementioned objectives, the systematic bibliographic review methodology was used, which is an instrument for mapping works published in books, articles, academic works (theses, dissertations and end of course papers), among others. It has an exploratory character, as allows the researcher to be able to create a synthesis of existing knowledge on the subject (BIOLCHINI et al., 2007).

For this methodology, the following steps were carried out, as defined by Kitchenham (2007): i) Sampling topic definition; ii) Database choice; iii) Search string formulation; iv) Search in the database; v) Preparation of the raw portfolio of works; vi) Work selection; and vii) Data extraction.

The sampling topics were related to tire disposal alternatives, such as reuse, reprocess and recycling.

Considering that the objective of this work was established in scientific article and academic work exploration, searches were carried out in the Google Scholar database using the search strings: "tire", "reuse of tires", "tire recycling" and "tire recycling methods".

After obtaining the raw portfolio, the following selection filters were applied:

- Works published between 2010 and 2022. This period was chosen due to the 12 years of PNRS approval.
- Scientific articles published in journals or academic works

After selection, the works were read in full to extract the data to be analyzed.

3 RESULTS AND DISCUSSIONS

After reading the works relevant to each aspect investigated, reuse, reprocess and recycling of unserviceable tires, those that stood out for their contribution were selected for analysis. Relevant data was extracted from the selected works, with 23.1% of the articles related to reprocess and 76.9% addressing unserviceable tire recycling.

3.1 Unserviceable tire recycling collection and disposal

According to RECICLANIP (2023), in 2018, 458 thousand tons of unserviceable tires were collected and disposed of in Brazil. In this same year, according to data from ETRMA, Brazil was ahead in absolute numbers from countries such as France, Italy, Poland, Turkey, Spain, Sweden, Netherlands, Portugal, the United Kingdom and Germany.

Brazilian manufacturers disposed of more than 380 thousand tons of waste tires in an environmentally friendly manner in 2020. In 2020, around 90 trucks collected a ton of unserviceable tires from collection points distributed throughout Brazil every day. From 1999 to 2020, more than 5.6 million tons of unserviceable tires were collected and properly disposed of, the equivalent of 1.1 billion passenger tires. The number of tires disposed of is mapped to the number of tires sold for replacement (RECICLANIP, 2023).

Collection points are established through partnerships with private companies and city halls, which provide space within specific safety and hygiene standards. This location is used to allocate unserviceable tires, until the minimum loading of 2,000 automobile tires or 300 cargo tires is reached, coming from various sources, such as tire shops, dealers and citizens themselves, to then continue to their final destination (RECICLANIP, 2023).

There are several ways to recycle, reuse and/or reprocess unserviceable tires, ranging from disposal for industrial processes, chemical incorporation into other materials, crafts, and incorporation into civil construction processes. In Brazil, the most common means of disposal are deposition in landfills or dumps, and the most used alternative means of disposal are the

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recovery of materials through the production of rubber artifacts or use in non-polymeric materials (asphalt, rubber, concrete, mortar), reuse in rubber flooring, rainwater drainage, marine artificial reefs, floating in ports, road protection, use for generating energy through burning or obtaining oils and gases, etc. (CARDOSO, 2015).

Figure 1 shows the tire cycle from the moment of its manufacture, maintenance until reprocess.

Figure 1 - Tire life cycle

Source: RECICLANIP,2023.

Unserviceable tire reuse serves to extend the tire's lifespan, therefore delaying its replacement with a new tire, before it becomes unusable and needs to be reused in other ways than for use on vehicles.

Reusing an unserviceable tire consists of giving the disposed product a new purpose, maintaining its original shape, or making small changes.

Recycling an unserviceable tire is transforming it into a new product through an industrial process that involves collecting, separating, cleaning, crushing and transforming materials into new products.

IBAMA, through the Waste and Emissions Control Coordination, linked to the Environmental Quality Directorate General Environmental Quality Management Coordination, is responsible for controlling and supervising the implementation of CONAMA Resolution 416 of September 30, 2009, which provides for the prevention of environmental degradation caused by unserviceable tires and their environmentally appropriate disposal. It determines that manufacturers and importers of new tires, with a unit weight of more than two kilograms, collect and properly dispose of unserviceable tires existing in the national territory and establishes the implementation of collection points for unserviceable tires in all municipalities with a population greater than one 100 thousand inhabitants (BRAZIL, 2009).

3.2 Reuse

The reused tire has the same purpose for which it was designed; it undergoes a renovation in which its carcass is reused, thus increasing its lifespan. According to item IV of Article 1 of CONAMA Resolution 416/2009, reuse processes are:

a) Recapping: process by which a used tire is reformed by replacing its tread with new tire rubber, extending the lifespan of the used tire carcass.

b) Retreading: process by which a used tire is reformed by replacing its tread and shoulders, increasing the tire's lifespan by 40% and saving 80% of energy and raw materials compared to producing a new one.

c) Remolding: process by which a used tire is reformed by replacing its tread, shoulders and the entire surface of its sidewalls.

By analyzing Figure 2, it is possible to understand the difference between each type of retread, based on the detail of each part of the tire, which is replaced in each of the tire retreading procedures mentioned above (recapping, retreading or remolding).

Figure 2 – Description of tire parts

Source: Achei Pneus, 2023.

3.3 Reprocess

Reprocessing unserviceable tires in handicrafts, despite being a way of reducing the impact generated by this waste, is a form of alternative disposal that uses a very small amount

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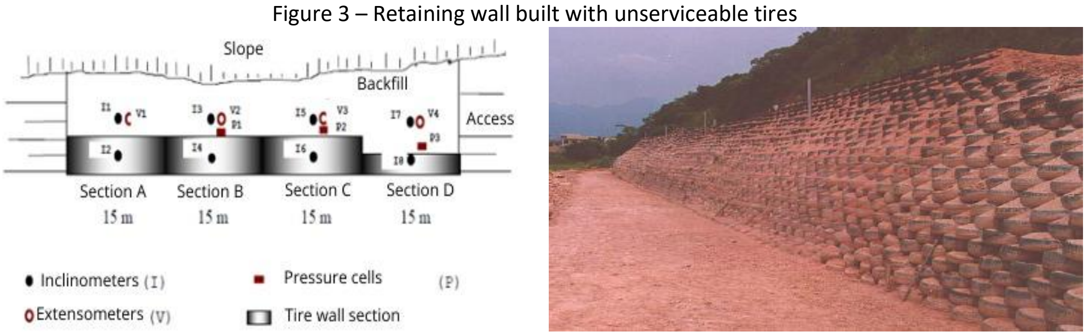
of tires, thus making other disposal methods necessary that use a greater amount of this residue. When reused for crafts, they can be transformed into tables, chairs, armchairs, mirrors, swings, vases, ottomans, sideboards, sofas and even bathroom sinks, among others (UCKER *et al.*, 2017).

In civil engineering, a very effective way to reprocess unserviceable tires is to use this waste as an alternative material in retaining wall construction, as described by Matos and Andrade (2022). Figure 3 exhibits an example of the construction of an experimental retaining wall 60m long and 4m high with horizontal layers of tires filled with compacted soil, where the tires were tied to each other by polypropylene ropes or steel wires gabion. A 2m layer of compacted soil was placed above the backfill to generate an overload. The wall was divided into four sections differentiated from each other by tire mooring, geometry and configuration (cut or whole). In Figures 3 "a" and "b", it is possible to see how tires were organized on the wall.

Figure 3 – Retaining wall built with unserviceable tires



(a) Schematic plan (b) Wall under construction

Source: Medeiros et al., 2000.

After several characterization tests to obtain the average values of grain density (Gs), Atterberg limits (PL and LL), plasticity index (PI) and natural moisture content, it is possible to state that "Tire reprocess in construction of retaining walls proves to be an effective technique. The case study showed that the reuse of tires in slope containment works is a good technically and economically viable alternative when compared to conventional slope stabilization techniques." (MATOS; ANDRADE, 2022).

However, despite showing a good alternative for reusing unserviceable tires, it is believed that this is an understudied solution, given the difficulty in finding other authors discussing this topic.

3.4 Recycling

Unserviceable tires can be recycled in several ways, such as co-processing (fuel source), lamination, rubber artifacts and rubber asphalt, as shown in Figure 4, where some examples of unserviceable tire recycling are presented.

Figure 4 – Examples of recycling unserviceable tires (1 - playground rubber flooring, 2 - asphalt -rubber, 3 - athletics tracks, 4 - synthetic grass sports surfaces)

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Source: adapted from ECOPNEUS (2023).

Around 70% of unserviceable tires are used as an alternative fuel in cement kilns, replacing petroleum coke due to its high calorific value (RECICLANIP, 2023).

According to ECOPNEUS (2023), energy production from unserviceable tires is carried out mainly in cement factories. This makes it possible to better exploit the high calorific value of rubber, comparable to that of petroleum coke. Its high burning temperatures guarantee compliance with emission limits. Furthermore, using this process makes it possible to recover ash and steel as combustion waste materials. They are then included in the final product, thus avoiding using other virgin raw materials and also generating an environmental and financial benefit for companies and society.

Some of the characteristics of unserviceable tires that make them a promising material for energy production, according to ECOPNEUS (2023), are:

- High caloric value;
- They replace other fuels richer in negative components, thus improving the quality of emissions from plants;
- In cement production, functional use also of the steel present in the tire.

According to the Brazilian National Cement Industry Union (SNIC, *Sindicato Nacional da Indústria do Cimento*), there are 91 cement factories installed in Brazil, 38 of which are licensed by environmental agencies to co-process waste (SNIC, 2016).

Each kilogram of tire releases between 8.3 and 8.5 kilowatts per hour of energy. This energy is up to 30% greater than that contained in 1 kg of wood or coal. The paper and cellulose industries and lime factories are major users of tires in boilers, using the entire carcass and taking advantage of some oxides contained in the metals of radial tires.

Non-radial tires are cut into sheets that are used to manufacture belts (furniture industries), shoe soles, rainwater ducts, etc.

The rubber removed from unserviceable tires gives rise to various artifacts, including car mats, industrial flooring and flooring for sports courts. Rubber floors provide a sustainable solution for unserviceable tires. They are versatile and can be used both indoors and outdoors, as they withstand variations in temperature and humidity. Floor installation and maintenance is simple, which makes it ideal for places with a large flow of people, such as playgrounds, playgrounds and gyms (AMET, 2023).

Recycled rubber is an excellent material for creating playgrounds due to its resistance, which also guarantees that it will last a long time. They can be made by joining prefabricated mats together or by coating on-site a mixture of colored rubber granules with polyurethane resins to create a unique surface (ECOPNEUS, 2023).

In different sports surfaces, recycled rubber is used to make the performance layer beneath the playing surface. The mixtures used are designed to obtain adequate shock absorption and an optimization of the return of elastic energy. In turn, the latter provides a perfect response to the athlete's biomechanical needs. It also reduces muscle fatigue, reduces microtraumas and improves sports performance. Multifunctional sports surfaces with recycled rubber can be made by "melting in place" a mixture of rubber granules and polyurethane resins or by assembling prefabricated mats in recycled rubber to form a single surface. In both cases, a colored acrylic resin is then applied over the rubber layer. This ensures correct adhesion. The marking lines to define the fields/courts are then applied to the colored resin. These are the types of surfaces present, for instance, in schools, in sports centers, for indoor and outdoor installations, or in gyms, and are suitable for almost all sports, from volleyball to basketball, from gymnastics to dance (ECOPNEUS, 2023).

The use of aggregates made from tire waste is an effective method to achieve sustainable development. The construction industry has been committed to developing sustainable resources, focusing on innovations and using recycled materials for limited natural aggregates (TANG *et al.*, 2021).

The incorporation of rubber aggregates into concrete changes its properties. In general, concrete density decreases with an increase in the amount of rubber aggregates, and this is due to its low specific weight compared to natural aggregates. An optimum amount of rubber aggregate can be used without changing the concrete properties. However, it is feasible to use a greater volume of rubber aggregates in concrete to improve acoustic insulation (KHERN *et al.*, 2020).

Using recycled rubber powder as an additive in mortar provides greater resistance to corrosion and reduces the heat of moisture of the mixture when compared to common mortars (AHMED *et al.,* 2019).

Recycled granulated rubber can also be used as a structural filler in foundation systems for low-rise, lightweight residential construction. When used in sizes similar to gravel at a content less than or equal to 40%, it presents adequate resistance, low compressibility and excellent energy absorption properties (TASALLOTI *et al.,* 2021).

By adding rubber powder to asphalt bitumen, it is possible to obtain road pavements with better mechanical performance compared to conventional bitumen. The advantages of asphalt modified with recycled rubber powder according to ECOPNEUS (2023) are:

- Reduction of noise generated by the tire in contact with the road;
- High pavement durability and excellent resistance to aging, with international experience of lifespans up to three times longer than traditional asphalt;
- Greater surface resistance to cracking. This leads to the consequent containment of maintenance interventions, with a reduction in the inconvenience caused by maintenance works and their respective costs;

- Greater safety due to excellent grip, water drainage with consequent noticeable reduction in the effect of splashes and spray in case of rain and improved visibility (ECOPNEUS,2023).

Adding shredded unserviceable tires into the asphalt mixture can not only improve various asphalt performances, but also provides an environmentally friendly way to recycle unserviceable tires (XIE *et al.*, 2023). According to ROMANELLI (2019), when paving 1 km of highways with rubber asphalt, reuse can vary between 600 and 1,000 tires. According to ECOFLEX (2023), in Brazil, in 2022, the mark of 16 thousand kilometers of asphalt-rubber was reached.

Using recycled tire rubber in asphalt pavements can reduce the permanent deformation of these flexible pavements as well as increase their rutting resistance, reduce pavement construction and maintenance costs, as they have better fatigue resistance (SAUD; AHMED; MONCEF; 2020).

According to YU et al. (2020), using rubber from unserviceable tires as an asphalt modifier, in addition to the previously mentioned characteristics, also reduces the asphalt mixture temperature in the paving process, which facilitates its execution.

4. CONCLUSION

From the data presented in this article, it is possible to conclude that properly disposing of unserviceable tires, whether through reuse, reprocess or recycling, has an important relationship with the application of reverse logistics for tires, given the damage that this product can cause to the environment and human health if it is disposed of incorrectly, and also the potential that it has to be used in several other ways and in several other sectors of the economy in addition to the automobile sector.

Tires after their lifespan can and should perform another function, as they are much more than a non-biodegradable residue that will take approximately six hundred years to decompose. Tires are a raw material very rich in elasticity as they contain rubber in their composition, and they can add this characteristic to concrete, mortar and flexible pavements (rubber floors). They are a fuel with great calorific value that can be used by different industries, saving the use of natural fuels. They are also a versatile material that can be reused in different ways without needing to be crushed or burned, ranging from artisanal products such as vases and armchairs to application in civil construction, serving to contain slopes.

The importance of giving tires a new destination is highlighted, in order to save the use of other finite natural resources and reduce the amount of solid waste that takes up a lot of space in landfills, dumps, valley bottoms, and other places.

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