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LITERATURE REVIEW OF COCONUT SHELL AND FIBERS IN PAVEMENT DESIGN

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The construction industry faces the challenge to balance the growing demand for new infrastructure and the sustainable use of resources that are generated throughout the different stages of civil infrastructure work. Other industries use materials that leave behind great amount of waste, that often their biodegradation and recycling processes are complex. To find avenues to adapt or incorporate such materials into the productive cycle, characteristics and mechanical properties studies are necessary. For example, due to the large consumption of coconut water, the elimination of these resources has generated major problems such as environmental pollution, methane emissions, insect outbreaks, reduction of the useful life of landfills and increased costs of maintenance of cities. However, research has demonstrated that coconut fibers and shells may be utilized in concrete applications. This study provides an in-depth review of the literature to learn about the current state of the art in the use of coconut fibers and shells as aggregates in pavement mixtures. Thanks to new technologies, it has been possible to carry out a more in-depth analysis regarding the use of environmentally friendly materials to be used in civil infrastructure works. The incorporation of the shell and coconut fibers are aimed to determine its influence on asphalt mix, considering the amount to be used and its long-term performance and to provide a new technology engineering in the construction of sustainable roads and highways using available ecological material.

Keywords: Sustainable pavements, Natural coarse aggregate, Substitute of coarse aggregate, Sustainable materials.

1 INTRODUCTION

The constant growth in world population has pushed to a worldwide growth of the demand of natural resources and energy followed by severe environmental degradation. Along with the increased consumption, new research focusses to find new alternatives such as sustainable energy and the reuse of natural materials in the construction industry. Nowadays, tons of natural materials are turned into waste, leading to a more polluted and contaminated environment. The building industry accounts for 36% of worldwide energy consumption, over 40% of total direct and indirect CO_2 emissions and for more than 45% of waste generation (Khatib 2016). The energy demand of buildings and their construction continues to increase due to better access to energy in developing countries. The preservation of the environment is an important concern in industrialized as well as developing nations, as construction is not an environmentally friendly process. Construction has a significant direct and indirect impact on the environment (Enshassi *et al.* 2014) and is the primary source of environmental pollution when compared to other industries, pointing out that any construction process requires various machinery, and natural resources that releases pollutants into the air. Some of these pollutants include air pollution, noise, solid waste, liquid waste, and water contaminants that release toxic gasses and dust. Construction projects, on the other hand, are the

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driving force behind the national economy, with major power consumption, environmental emissions, and social effect (Dehghani *et al.* 2017).

Nowadays, it is becoming common practice for asphalt mixture production all over the world to use a recycled asphalt pavement material composition of between 15% and 20%. For example, as well as Dutch contractors, who managed to select their own mixing and design composition by proceeding with rejected materials if they meet the final performance requirements (Meroni *et al.* 2021).

According to the European Plastic Manufacturers Association, plastic consumption has surged by 40% over the previous decade. This represents around 359 tons produced in 2018 (Lastra-González *et al.* 2022). The significant growth in plastic has created an environmental concern due to the time it takes to totally decay. As a result, it is vital to identify innovative ways to recycle this garbage. Furthermore, the production of bitumen has an environmental impact on the construction of highways. Given the energy consumption and pollutants produced during oil cracking, bitumen requires heating during manufacture to obtain appropriate workability. In addition, bitumen has an economic influence, accounting for 60% of the overall cost of the entire mix. Replacing bitumen with plastic waste in asphalt mixes might be helpful both environmentally and economically. Extensive research has been carried out to reduce the environmental impact around the construction industry to reuse, reduce and recycle materials for the construction of civil works and reduce the number of emissions released to the environment. For this reason, an analysis of the use of the shell and coconut fiber will be carried out to look for a substitute for partial aggregates in pavement mixtures in to give a second use to this material found in enormous quantities instead of being a threat to nature being a source of contamination.

2 METHODOLOGY

This study uses a systematic literature review (De Carvalho *et al.* 2017) of the practical application of coconut fibers and shells as partial substitute in coarse aggregate for pavement design, including both rigid and flexible pavements. This research is directed based on several scientific articles from which it has been possible to reach practical conclusions, so they could be analyzed in this work. The unit of analysis for this project is a single research article. The first filter to select a research paper was based on scope. This article focuses on scientific article literature only. For the research of these official documents, keywords such as “green pavement”, “coconut fibers and shells”, “environmental impact”, “natural aggregates” and “coconut fibers and shells in the development of pavements” were used. Then, researchers considered classification and evaluation in published studies. Regarding classification, the type of documentation that would be applied and reviewed in the literature for its structuring and classification was selected and defined. Regarding evaluation, the analyzed material is ordered and classified according to the context of the classification. This allows the identification and interpretation of the results.

Inclusion and exclusion criteria were followed with respect to the selection of reviewed articles. This review included several types of articles taking into consideration the use, performance, feasibility, and environmental impact of the application of coconut fibers and shells in pavements design. A total of 31 articles published in academic journals from January 2011 to September 2022 were selected. For each document, an individual summary was made, focusing on its investigation in greater depth. This information allowed researchers to organize the data according to themes. The themes are “use of coconut fibers and shells in pavements”, “natural materials in pavement”, “efficiency and feasibility of the use of coconut fibers and shells in pavements”. The exclusion criteria helped to limit the number of publications, empirical articles that mainly addressed specific operational questions were excluded, as well as highly technical works on social and economic

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issues and research with a highly ecological perspective were excluded as well as information not relevant based on the objective of this article.

Data was entered into a spreadsheet, and a meticulous process was followed to assure the quality and dependability of the data acquired. As mentioned before, the authors carefully read the publications obtained and collected data using an abstract in which the most important data was reported. Finally, weekly meetings were held to discuss the information obtained.

3 RESULTS

After an analysis of the 31 scientific documents that refer to the incorporation of coconut fibers and shells in the pavement design and development, the articles were grouped according to their area of contribution within six categories. Table 1 shows the categories according to the knowledge subdivision and a short description of each category.

Table 1. Categories of knowledge division.

Category	Category Description	Articles Containing These Categories
Coconut shell	Coconut shells are placed in different percentages in the pavement mix, thus obtaining increases in their mechanical properties.	(Jeffry *et al.* 2016, Limantara *et al.* 2019, Girish *et al.* 2020)
Coconut fiber	Coconut fibers, which vary in length, have good mechanical characteristics against vehicular loads such as traction and adhesion.	(Oda *et al.* 2012, Hadiwardoyo 2013, Sumesh *et al.* 2015, Che Wan *et al.* 2019, Gopala Rao and Sowjanya 2019, Maharaj *et al.* 2019, Rachman and Syammaun 2019, Figueroa 2020)
Coconut shell and fiber	The union of the shell and the coconut fiber as part of the pavement mix allows impressive results in terms of resistance, stability, and porosity.	(Ting *et al.* 2015, Ting *et al.* 2017, Limantara *et al.* 2018, Ting *et al.* 2018, Haryati *et al.* 2019, Norhidayah *et al.* 2019, Castro Jerónimo *et al.* 2020)
Coconut shell and fiber in asphaltic concrete	The implementation of coconut shells and fibers in rigid pavements results in modifications of their physical and mechanical properties, demonstrating an improvement in their stability, resilient modulus and creep stiffness.	(Jeffry 2015, Naveenkumar *et al.* 2018, Fernández Acosta 2019, Rahman *et al.* 2020, Ramadhansyah *et al.* 2020, Nayak *et al.* 2022)
Coconut shell and fiber in block pavement	The use of shell and coconut fiber in articulated paving allows to obtain lighter, cheaper and better-quality blocks, thus achieving a benefit for the environment.	(Kassim and Rohim 2017)
Coconut shell ash/ nanomaterials	The coconut shells in the form of ash used as a nanomaterial improved its strength and hardness, generates a homogeneous structure and increases the cohesion and adhesion of the bitumen.	(Abdullah *et al.* 2017, Jeffry *et al.* 2018a, Jeffry *et al.* 2018b, Syammaun *et al.* 2019, Jeffry *et al.* 2020, Molvi and Singh 2022)

4 DISCUSSION

From the information obtained and analyzed, it was decided to divide into six subgroups which have as a specific objective in the analysis of a fixed study based on each category. The six subgroups were divided into scientific articles containing detailed information based on the following topics: coconut shells, coconut fibers, coconut fibers and shells, coconut fibers and shells in rigid flooring, coconut fibers and shells in articulated pavement (block pavement), and coconut shells in ash form; in order to get a better view of the progress made so far and thus be able to decipher the gaps or empty spaces within the literature based on this topic.

As mentioned above, around **flexible pavements** there is a large amount of information regarding the use of coconut fiber and shells in bituminous mixtures in which several tests have

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been carried out to know their properties and mechanical characteristics. On the other hand, on rigid and articulated pavements, there is not enough information. Researchers must cover all areas of knowledge on this topic, since, when conducting the literary review, only a few scientific articles focused on this topic. For **rigid pavements**, it is known that the coconut shells are replaced in a specific percentage compared to coarse aggregate which makes up an excellent concrete mix. In addition, to the great mechanical properties that coconut fiber provides to the mix. Regarding to articulated pavements, not enough information was found despite the lack of knowledge in this area. As there are very few scientific articles based on this subject, it is recommended that this branch must be investigated in greater depth and carry out a greater number of tests that mark milestones in the incorporation of both coconut fibers and shells as part of the pavement mix.

A large amount of information was found (25 articles) on the use of **coconut fiber and shell for soil improvement**. Expansive soils mainly denote clay soils that tend to swell and shrink depending on their moisture content. These are considered a possible environmental risk that can cause substantial deterioration to structures if not addressed correctly, leading to serious construction, economic and social problems (Chakraborty and Roy 2016). The articles analyzed based on the stabilization of soils with the use of coconut fiber and shells several tests were carried out ensure an improvement in the properties of the soil, assuming that the coconut husk is efficient in improving the qualities of the expanding soil, considering that these waste materials are a cost effective and environmentally friendly method (Ashish Johnson and Krishnankutty 2017).

The incorporation of **coconut shell in concrete** has grown in favor in recent years due to its lightweight composition and outstanding thermal insulation capabilities (Gunasekaran *et al.* 2011). Construction industries value the underlying economies and benefits afforded by these materials, as proven by its lightweight concrete constructions (25-35% lighter). Concrete containing natural waste materials such as coconut shells, structural lightweight concrete (LWC) offers incredible versatility in construction and cost savings due to self-weight loss, impressive seismic structural response, cheaper foundation rates, and "precast concrete elements" by being lightweight, offers reduced transportation and placement costs (Gunasekaran *et al.* 2011). Due to the great knowledge of the use of coconut fiber and shells in **structural concrete** and in **soil improvement**, it is possible and important to carry out an in-depth investigation of the application of these elements in pavements. Additional research is needed for its application and utilization on roadways worldwide, thus opting for a more proactive culture of environmental care and providing efficient, sustainable, economic, and friendly help for the environment that surrounds us.

5 CONCLUSION

An extensive literature research has been performed on the application of coconut fiber and shell as a replacement component of coarse aggregate for use in pavements. The project helps to understand that there are several uses for which this natural material can be used for construction works in highways. The information was categorized in six subgroups regarding the different applications and uses of this natural material. It was concluded that these wastes, which are considered waste materials, it is possible to give them a second use to fulfill a different function. Based on what has been analyzed and studied in this work, it can be said that coconut fibers and shells can work as a partial substitute for coarse aggregate for various types of pavements, achieving improvements in their physical, chemical, and mechanical properties, providing optimal properties for their application.

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