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Systematic Literature Review for The Use of Polypropylene as Stabilization or Reinforcement Material for Road Paving Bases and Sub-bases

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Abstract **-** This article addresses the use of plastic waste of the polypropylene type in civil construction in infrastructure works, especially as a material for reinforcing and stabilizing soil in the bases and sub-bases of paving intended for road transport. Through a systematic bibliographical review and with the aim of showing the state of the art about this practice, it can be understood that plastic waste can be used as aggregates or additions to the soil to stabilize or reinforce bases and sub-bases of floors. Contributions were found on methods, laboratory testing procedures, type and format of materials as well as their respective compositions and dosages. The results obtained in the studies analyzed showed discoveries and indications and limitations to the use of this material in its various formats. This work is important because, given the growing search for sustainable solutions to reduce the environmental impacts of plastic waste, it contributed by presenting research in several countries and continents with significant gains in physical-mechanical properties with reports of experiences that achieved improvements of up to 200% in compressive strength of unconfined soil, among other indicators of improvements in the original soils.

Keywords**:** soil reinforcement, soil stabilization, plastic waste, polypropylene grains, paving base and sub-base.

1. Introduction

1.1 Plastics and the environment

Thermoplastics are used practically by all sectors of the economy and modern life: construction, agriculture, clothing, footwear, furniture, food, textiles, leisure, telecommunications, electronics, automobiles, aeronautics, sporting goods, medicine and hospitals, energy, in addition to replacing organic, ceramic, metallic, polymeric and composite materials [1].

Since the invention of synthetic plastic created between 1869 (celluloid) and 1909 (phenol formaldehyde), other types of plastics have been developed and transformed into initially semi-durable artifacts, replacing several materials with advantages [2].

Non-durable and disposable consumer items had their substantial production around the 1940s and more exactly in the period between World War I and World War II and reached, from 1962, more than one million tons per year of thermosetting and thermoplastic plastics, mainly polyethylene plastics. Since then, and almost uninterruptedly, the world production and consumption of plastics has been increasing at an average rate of 8% per year [3].

From 1950 to 2015, the world production of plastics grew from 2 million tons to 407 million tons annually. As a result, it is estimated that, as of 2022, about 8.3 billion tons have been produced, of which 6.3 billion tons have been discarded. Of this amount discarded, only 9% was recycled, that is, approximately 567 million tons. Of the remaining amount, 12% were incinerated and 79% were discarded in landfills or the environment. In 2021, the global production of plastics was 390.7 million tons [4]. Figure 1 summarizes the world production of plastics in 2021:

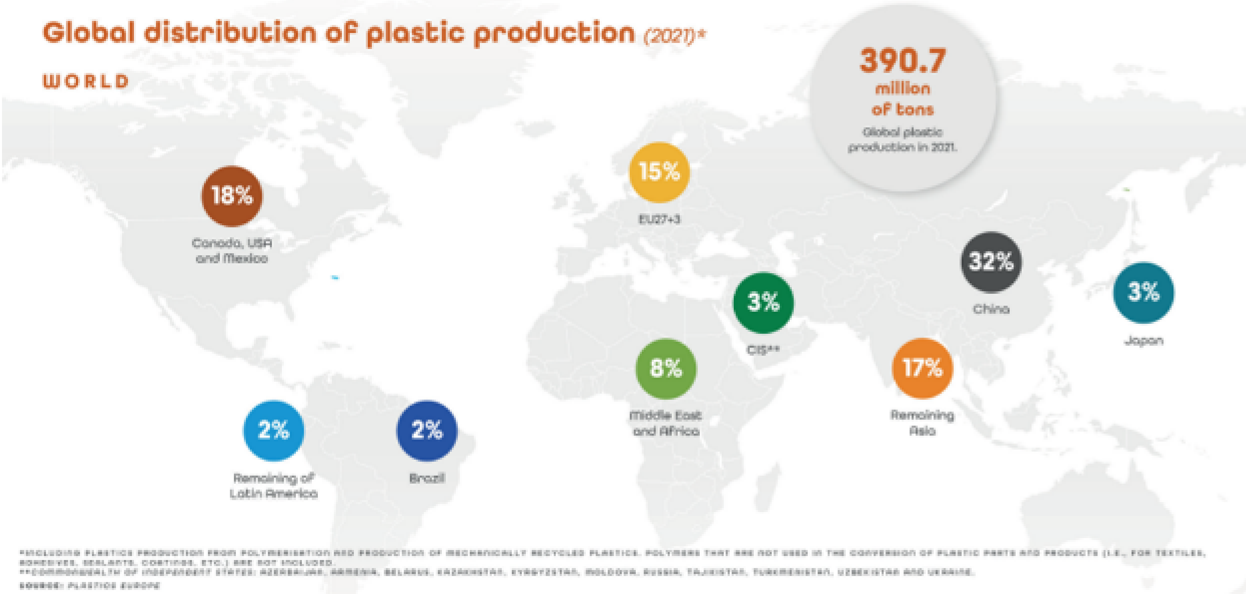

Figure 1: Global distribution of plastic production in 2021. Source: [4].

Researches and the media in several countries continuously report the presence of post-consumption plastic waste found in the most unusual places on the planet, including soil, air, oceans, rivers, north and south glacial poles, in addition to urban and rural settings.

Currently, this is one of the main global problems and, as a consequence, plastic pollution has serious environmental implications for fauna, flora and common goods such as water and atmospheric air. In addition, it leads to social, economic and public health problems, since much of the plastic waste generated annually is far from being managed in compliance with the objectives recommended by the United Nations through the 17 sustainable development goals.

Unlike data from ABIPLAST [4] , according to Alliance To End Plastic Waste [5] in the same year of 2021, world production would have reached 461 million tons. Regardless of the data sources and data collection methods, the figures are impressive considering the average of 425,000,000 tons for materials whose density is between 0.900 g/cm3 and 1.400 g/cm3, respectively polypropylene – PP and polyvinyl chloride – PVC.

Researchers suggest that we are living in a new anthropological era that could be called The Age of Plastic [6].

According to data from the Alliance to End Plastic Waste [5], the expected growing trend ranges from 1 to 5% per year in the plastic resins business worldwide. The largest producers are Asia, North America and Europe introducing 40%, 19% and 14% of the total plastic put-on-market in 2021, respectively.

1.2 Plastics in Brazil

According to data from the Brazilian Association of the Plastic Industry – ABIPLAST, in Brazil in 2022, the physical production of transformed plastic products from virgin resins was 6.7 million tons and the main resin consumed was Polypropylene (PP) with 20.3%, followed by High Density Polyethylene (HDPE) with 16.1%. In the case of production from recycled post-consumer plastics, the estimated production was 1 million tons, with Polyethylene Terephthalate (PET) being the most recycled plastic with 39.8%, followed by High Density Polyethylene (HDPE) with 19.9% and Polypropylene (PP) in third place with 16.9%, as shown in Figure 2 [4].

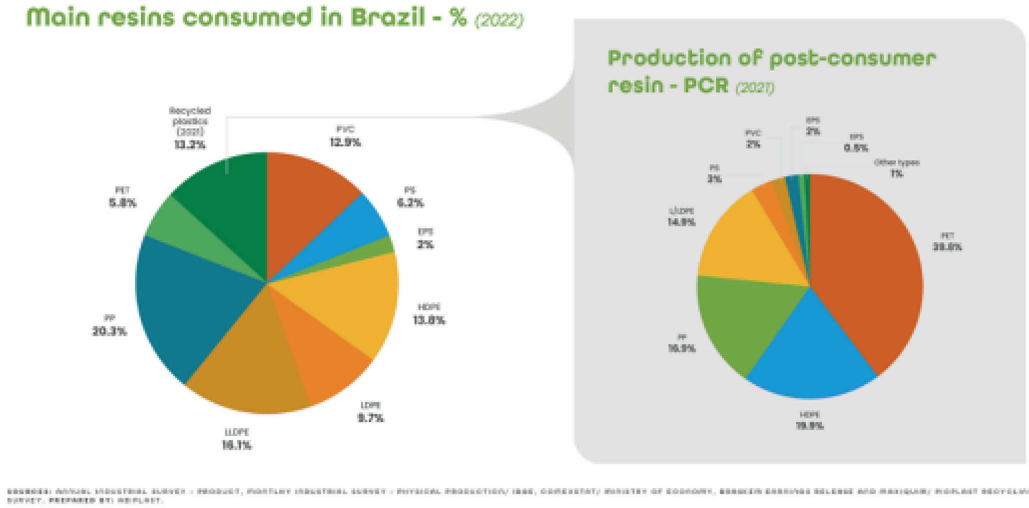

Figure 2: Main resin consumed in Brazil (%) in 2022. Source: [4].

According to [4] and considering that the amount of plastic waste was 4.3 million tons, the recycling rate in the period of 2021 to 2022 was 23.4%, with PET being the most recycled plastic with 54.4%, as shown in Figure 3:

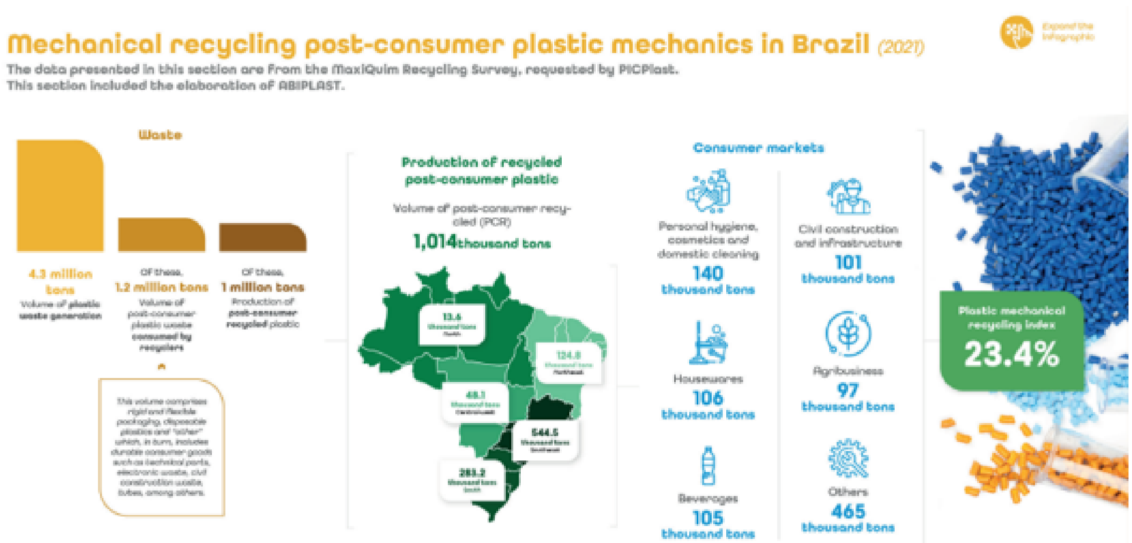

Figure 3: Mechanical recycling of post-consumer plastic in Brazil in 2020. Source: [4].

Civil construction, for example, consumes 25.4% for pipes, connections, frames, electrical material, among other products considered of medium or long duration because their life cycles are usually over 5 years. The food, beverage, pharmaceutical and disposable sectors consume 30.6% practically destined for packaging and, notably, of this amount of plastics, 40.1% are products with a life cycle of less than 12 months and 18.5% are products with an average life cycle of 1 to 5 years, that is, almost 60% of plastic products are considered disposable or goods with a short or medium life cycle [4].

In the forecasts presented in the Plastic Atlas 2020, by the Heinrich Böll Foundation [7], if the plastic production, consumption and disposal trends on the planet are maintained, it is estimated that, by 2050, plastics manufacturing could emit 56 Giga tons of CO_2, equivalent to 13% of the estimated limit of CO_2 emissions so that global warming does not exceed 1.5°C.

1.3 Cement-based or soil-based composites

Among the materials used in cement-based and soil-based composites, the systematic reviews include national and international research on glass fibers, wood fibers, polypropylene fibers, polypropylene flakes, PET flakes, ground polypropylene, ground PET, rice husk ash, graphite polyethylene nano composites, ground rubber, EPS, PVC, blast furnace slag, and construction and demolition waste – CDW, among others. Suggested applications range from the production of architectural artifacts, prefabricated construction elements, housing buildings and paving works.

1.4 Polypropylene

Regarding polypropylene, the researches represented by the sample of selected articles most often use the formats of linear fibers, smooth cylindrical pellets, smooth cubic pellets and smooth laminar flakes, which, in most cases, are industrialized materials obtained from primary resins, with few experiments with recyclable plastic waste. Among the 4,111 documents, none used grains with spherical or similar shapes and simultaneously combined with striae or fibers. The use of synthetic industrialized fibers obtained from virgin or primary resins is more substantial, rather than products derived from recycled plastic waste.

1.5 Soils: stabilization and reinforcement

According to [8], soil can be defined as a combination of gravel, sand, clay and silt, characterized by having low tensile and shear strength and with properties that can vary according to environmental conditions, dry or wet material. The correction or reinforcement of physical-mechanical weaknesses consists in the use of several technologies, independently or in combination, whose purpose is to provide the mass of composite soil with improved stability, increased tensile and compressive strength, and reduced settlements and deformations recurring from lateral forces. Figure 4 shows some soil reinforcement procedures:

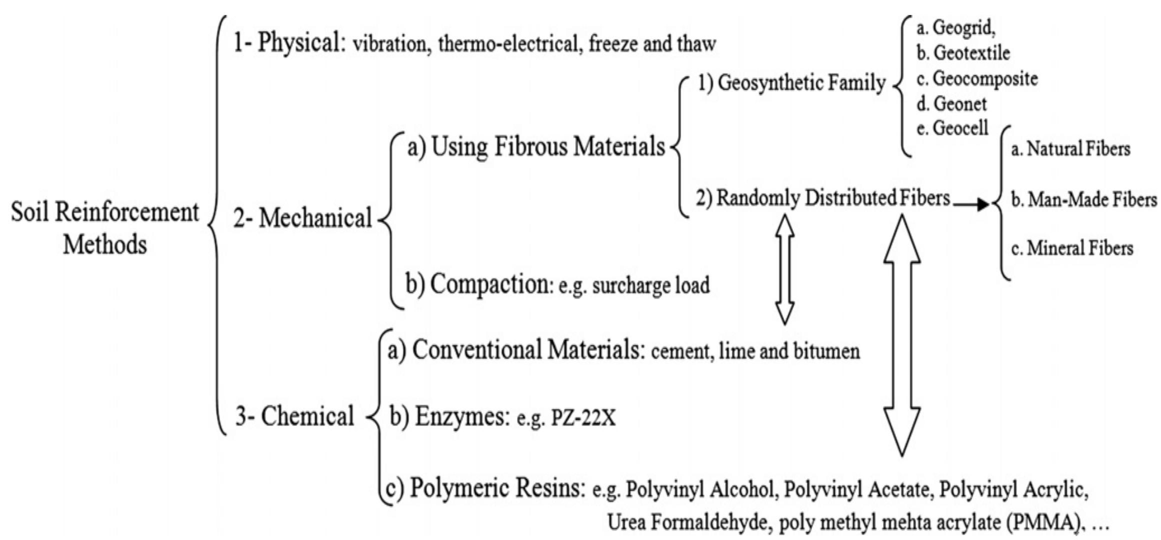

Figure 4: Different soil reinforcement procedures [8].

Brazilian roads are designed and built with the challenge of overcoming major geological, meteorological, climatic, and topographic variations, among others. This is due to the fact that they are intermunicipal, interstate and international and, in view of the variability of tropical soil types and characteristics in each region, it is possible to assume the demand for constant engineering and technologies to mitigate soil stabilization problems and the related needs for reinforcement of road paving bases and sub-bases.

2. Study Objectives and Contributions

2.1 Specific objective of the systematic literature review

The specific objective of the research is to trace, based on the state of the art and corresponding reviews, the initiatives for the use of recycled plastic, especially polypropylene, mixed with soil forming a polymer-soil composite with significant improvements in the original properties and characteristics of the soils studied, mainly related to the physical-mechanical compressive strength, tensile strength, and resilient modulus, among others, that represent indicators of delay in the emergence of defects that impact as reducers of useful life in paving for road transport. To this end, the recycled polypropylene agglutinated grain (GRAPP) will be studied.

2.2 Justifications

The importance of studying alternatives for recycling plastics can be justified by the fact that these polymeric materials have been replacing several types of ceramic, metallic, and organic materials for decades, and, in the case of polypropylene, there is a simultaneous and gradual replacement of other types of plastics in products and packaging previously manufactured with HDPE, LDPE and PET. As an example, soft drink bottles that have been popularly called “PET bottles” for decades can now also be called “PP bottles.” Given the ease of production in multiple formats, textures and geometries, recycled plastic has the potential to be used as a material in civil construction, either as an aggregate, admixture, component of composites, including mixed with soil in order to improve compressive strength, among other important physical-mechanical properties for stabilization of soils of bases and sub-bases intended for paving works in the transport area.

3. Research Questions

We can list 3 questions for this research:

Question 1: Are there sufficiently in-depth experiments in the literature to safely determine the use of recycled plastic combined with soils to be applied in paving works for road infrastructure?

Question 2: Is there a normative standard or standardized experimental model for the testing procedures, tests to parameterize the results obtained for decision-making on the use of the resulting polymer-soil composite?

Question 3: Is the use of recycled plastic a technically, economically and environmentally viable alternative for road paving works?

The systematic literature review will be the main source for collecting data and information whose analyses enable us to achieve the objectives described in item 2 and answer the questions formulated in item 3 and, based on the answers, it will be possible to find some research gaps as to the use of recycled plastic, especially polypropylene plastic.

For this procedure, we adopted the Systematic Bibliographic Review Methodology, which will be described below in item 4.

4. Methodology

A systematic literature review was conducted using UNICAMP’s library system, retrieving articles from Scopus, Web of Science, and Science Direct. The search strategy involved five filtering steps:

1. **Keyword Search:** Terms related to polypropylene, soil stabilization, and road paving were used, yielding 4,111 articles.

2. **Content Filtering:** Selecting full-text articles published in the last five years in English and Portuguese, reducing results to 1,848.

3. **Subject-Specific Filtering:** Limiting studies to materials science, civil engineering, and pavement technology, narrowing to 253 articles.

4. **Keyword Refinement:** Applying additional search terms, further reducing results to 155.

5. **Final Selection:** Evaluating adherence to research objectives, selecting 27 key articles, with 12 meeting all criteria.

Bibliometric analysis was conducted using VOSViewer 1.20, software to identify research trends and gaps.

5 . State-of-The-Art Literature Review: Summary

5.1 Main results found in the analyzed literature

Studies show that polypropylene in fiber, pellet, and granular forms improves soil properties. [9] reported up to 96.41% increases in unconfined compressive strength (UCS) with 0.3% fiber content, [8] found that fiber dosages between 0.2% and 4% enhanced soil stability and [10] observed over 200% UCS improvement in low-plasticity clay with 0.75% fiber content.

Abukhettala and Fall [11] tested various recycled plastic formats, concluding that polypropylene significantly increased California Bearing Ratio (CBR) values. [12] examined fiber length and distribution, finding that 35 mm fibers improved tensile strength by 40%. [13] studied cement-stabilized soil reinforced with polypropylene, noting UCS gains of 38.89%.

For airport runway applications [14] tested different fiber types, showing that thin and thick polypropylene fibers produced superior results. Evaluated the mechanical performance of asphalt modified with recycled plastics, [15] finding a 183% increase in shear modulus.

Interestingly, despite the formation of multiple research clusters, no interconnection between them was identified, suggesting variations in methodologies and testing standards. The review also highlights the need for deeper research into the durability, environmental impact, and cost-effectiveness of polypropylene soil composites.

5.2 Summary of main data found in the literature

Table 1, below, presents a summary of the main data found in the literature, considering the format of plastic materials, plastic material content in the admixtures, the types of soils studied, the main laboratory tests performed and the best results obtained:

Table 1: Summary of the studies analyzed in the systematic literature review

Source	Format	Content (ideal)	Soil Type (USCS)	Laboratory tests	Best Results Obtained
[9]	discrete and short polypropylene fiber (l=15mm)	0,3%	CL	1. Unconfined compressive strength varying fiber content and length 2. Shear strength varying fiber content and length	Increase of 11.79 to 96.41% in Simple Compressive Strength (SCS). Increase of 85.81% in cohesion and 31.22% improvement in the internal friction angle of the soil
[8]	discrete and short polypropylene fiber (l=15mm)	0.2 to 4% by mass	CL	1. Direct shear 2. Unconfined compressive strength ASTM D2166	Review of literature reporting experiments with increased unconfined compressive strength, reduced shrinkage deformations and expansion pressures of expansive clays.
[10]	discrete and short polypropylene	0,75%	CL	1. Unconfined compressive strength	Over 200% increase in unconfined compressive

	fiber (l=15mm)			ASTM D2166 2. Standard Proctor	strength
[16]	PET fibers	1,00%	MH	1. Axial compression tests (UU)	Increase in shear strength. Increased plastic deformation capacity. The cores added with discrete fibers did not reach the rupture state.
[17]	Short (15mm), long (30mm) narrow (2.5mm) and wide (7mm) PP fibers	0,5%	CH	1. Standard Proctor compaction test ASTM-D698	Longer fibers (30mm) contributed to reduce the swelling pressure of the soil while wider fibers (7mm) were more efficient to restrict swelling
[11]	HDPE, LDPE, PET and PP in flakes, pellets and ground	1%, 2%, 3%, 4%, 5% and 10%	SG type clayey and, sandy type A-2-7	1. California Bearing Ratio (CBR) – ASTMD-1883 2. Permeability Test ASTM-D5084 3. Unconfined compressive strength ASTM D-2166 4. Triaxial static shear test ASTM D-4767 5. Resilient modulus AASHTO T-307-99	For all types and forms of plastic, except those with crushed LDPE, there was an increase in CBR, on average 33% compared to the CBR of unmodified soils.
[12]	PP polypropylene fibers with 15, 22.5, and 35mm fibers	0.35%, 0.60% and 0.85% fibers with 15, 22.5 and 35mm fibers	Soil collected in the Shaanxi region of northwest China, distributed in the Loes Plateau of China.	1. Tensile strength ASTM C496	Tensile strength increases by an average of 35% the tensile strength with random distribution of fibers was higher than with discrete distribution, respectively 28.5% and 40% on average
[13]	Polypropylene fibers	0.8%, 0.6%, 0.6% and 0.45% respectively for the 6mm, 12mm, 14mm and 19mm fibers	Soil from the Dandong region, China, modified with admixture of Portland cement type stabilizing agent	1. Unconfined compressive strength ASTM D2166 2. Tensile strength ASTM C496	The unconfined compressive strength (UCS) exceeded 5 MPa, meaning an increase of 38.89%.
[14]	admixture of thin polypropylene fibers combined with thick polypropylene fibers	0,3%	Soil modified with addition of Portland cement type stabilizing agent	1. Unconfined compressive strength ASTM D2166	Addition of wide polypropylene fibers unconfined compressive strength (UCS) from 22.3 to 60.6 MPa
[15]	PW – a mixture of crushed HDPE, LDPE, PET and PP	10% by mass of bitumen	hot asphalt mastics composed of bitumen and filler.	1. Rheological characterization of asphalt mastics (shear modulus and phase	PW showed an increase in shear modulus values on average 183% higher than pure asphalt mastic

	JGW – jet grouting waste			angle). 2. Life cycle assessment (LCA)	and 53% higher than JWG.
[18]	Recycled HDPE and polypropylene – PP pellets (3 to 4mm)	4 to 12%. Ideal content was 8%.	clayey soil, type CH, with the addition of 9 to 15% Portland cement.	1. Unconfined compressive strength 2. Stress-strain 3. LCA	Up to 118% increase in capacity to absorb energy from plastic deformation

6. Analysis and Discussion of The Results

Here, we note five (5) noticeable gaps in the articles analyzed and that can feasibly be considered for future research:

1. Proposal for the modeling or standardization of test methods in favor of a common, broad and universal methodology and standard;
2. Standardization of scientific terminologies related to physicochemical properties, nomenclature of laboratory tests and terminologies that determine the characterizations of the materials tested;
3. Despite addressing environmental issues, especially in the introductions to the texts, most researches did not use recycled plastics. Most studies used fibers manufactured from virgin resins;
4. Lack of comparative analyses of technical, economic and environmental viability and,
5. Lack of research indicating which would be the most relevant laboratory tests for decision-making on the use of recycled plastics as materials to be added to soil seeking significant improvements to soil service performance in road paving works.

7. Final Considerations

Through the systematic literature review methodology, we observed in the state-of-the-art literature from 2013 to 2023 the growing interest and urgency in the development of innovative research with the potential to combine the solution of two problems, namely:

a) reducing the environmental impacts caused by the linear model of production, consumption and disposal of consumer goods, specifically referring to plastic materials, whose origin, characteristics, and global and Brazilian quantities related to production, consumption, disposal and recycling were elucidated, and,
b) reducing defects that occur in road paving infrastructures (in service or operation) resulting from base and sub-base soil problems, especially those caused by insufficient or weak support of axial and/or lateral loads, such as compressive strength, direct shear strength, and resilience modulus.

The articles analyzed focused on the application of plastic materials of different types and in different formats as materials to be used in admixtures with different types of soils forming a soil-polymer composite whose properties were improved by adding plastic materials in formats, dosage contents ranging from 0.3% to 10% of soil mass. The results showed, in certain studies, significant gains in physical-mechanical properties of up to 200% in unconfined compressive strength, 35% in direct shear strength, in addition to improving resilience modulus, the angle of friction between the soil particles rearranged and combined with the plastic particles. It should be noted that the improvement rates correspond to completely different studies and should be considered individually, on a case-by-case basis, and not in a generalized and broad manner.

This difficulty in the generalization of the results is due to the need: for more in-depth, detailed studies and also due to the lack of standardized laboratory test methods with pre-established standards and methods that determine precisely the properties to be characterized; for parameterization of the physical-mechanical limits of acceptance or rejection of these properties; for establishment of the methodology, system or set of standards and procedures as a general, comprehensive and universal framework.

Such gaps are present in the analyzed literature and are often mentioned or described by the researchers.

The researches showed creative and innovative aspects in obtaining results by combining laboratory tests through adapted traditional standards and, in some cases, by performing field tests, thereby enabling a practical assessment of the effectiveness of the findings of the tests and their adaptations.

8. Stage of our research at UNICAMP, Brazil:

At this time, March 2025, we have completed the characterization of materials including polypropylene (GRAPP) and are carrying out California Bearing Ratio - CBR tests to determine mixtures with ideal dosages based on granulometric analyses for soil-gravel.

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References

[1] Levy Neto, Flaminio; Pardini, Luiz Cláudio. Compósitos estruturais: ciência e tecnologia. 1. ed. - São Paulo: Blucher, 2006. ISBN 978-85-212-0397-1

[2] Callister Jr., Willian D.; Rethwisch, David G. Ciência e engenharia de materiais: uma introdução. Tradução: Sergio Murillo Stamile Soares. 9 ed. - [Reimpr.]. Rio de Janeiro: LTC, 2018. ISBN 978-85-216-3103-3.

[3] Subramanian, Muralisrinivasan Natamai. 2019. Plastics Waste Management, 2nd Edition. Scrivener Publishing LLC.

[4] ABIPLAST. Associação Brasileira da Indústria do Plástico. Preview 2022: As indústrias de transformação e reciclagem de plástico no Brasil. Disponível em:https://www.abiplast.org.br/wpcontent/uploads/2023/04/Preview2022_web.pdf Acessado em 25/06/2023.

[5] Alliance to End Plastic Waste: The Plastic Waste Management Framework. White paper by Roland Berger, 2023. Disponível em https://endplasticwaste.org/en/our-stories/plastic-waste-management-framework

[6] Rangel-Buitrago, Nelson; Neal, Willian; Willians, Allan. The Plasticine: Time and rocks, Marine Polluition Bulletin, v. 185. Part B, 2022. 114358, ISSN 0025-326X, https://doi.org/10.1016/j.marpolbul.2022.114358

[7] Atlas do Plástico: Fatos e números sobre o mundo dos polímeros sintéticos. Organização: Marcelo Montenegro, Manoela Vianna, Daisy Bispo Teles. 1. ed. Rio de Janeiro: Fundação Heinrich Böll, 2020. ISBN 97865-87665-02-3.

[8] Hejazi, Sayyed Mahdi; Sheikhzadeha, Mohammad; Abtahi, Sayyed Mahdi; Zadhousha, Ali. 2012. A simple review of soil reinforcement using natural and synthetic fibers. Construction and Building Materials.DOI: 10.1016/j.conbuildmat.2011.11.045

[9] H. Jiang, Y. Cai, and J. Liu, "Engineering properties of soils reinforced by short discrete polypropylene fiber," Journal of Materials in Civil Engineering, vol. 22, no. 12, pp. 1315–1322, 2010.DOI: 10.1061/(ASCE)MT.1

[10] Senol, Aykut; Ikizler, S. Banu; Etminam, Ehsan. 2014: Improvement of Low Plasticity Clay Soils Using Polypropylene Fibers. Monitoring, Modeling and Management of Pavement Performance GSP 254 ASCE 2014. DOI: 10.1061/9780784478547.001

[11] Abukhettala, Mukhtar; Fall, Mamadou. 2021: Geotechnical characterization of plastic waste in pavement subgrade. Transportation Geotechnics 27 (2021) 100472. DOI: 10.1016/j.trgeo.2020.100472

[12] Ele, Shixin; Wang, Xuxiang; Bai, Haibo; Xu, Zhiwei; Ma, Dan. 2021. Effect of fiber dispersion, content, and aspect ratio on tensile strength of PP fiber reinforced soil. Journal of Materials Research and Technology. DOI: 10.1016/j.jmrt.2021.08.128

[13] Hu, Cheng; Weng, Xing Zhong; Liu, Cong; Jiang, Le; Liu, Junhong; Li, Wenlei. 2021: Performance of Solidified Soil Reinforced with Polypropylene Fiber. Hindawi: Advances in Civil Engineering Volume 2021, Article ID 8859358, 16 pages https://doi.org/10.1155/2021/8859358. DOI: 10.1155/2021/8859358

[14] Zhang, Jun; Xu, Wei; Gao, Peiwei; Yao, Zhihua; Su, Lihai; Qiu, Nianyuan; Huang, Wei. 2022: Soil compressive strength characteristics cement reinforced with hybrid fibers. International Journal of Pavement Engineering: DOI:10.1080/10298436.2022.2104843.

[15] Russo, Francesca; Oreto, Cristina; Veropalumbo, Rosa. 2022. Promoting resource conservation in flexible road pavements using jet grouting and plastic waste as filler. Resources, Conservations and Recycling. DOI: 10.1016/j.resconrec.2022.106633

[16] Botero, E.; Ossa, A.; Sherwell, G.; Ovando-Shelley, E. 2015: Stress and deformation behavior of a silty soil reinforced with polyethylene terephthalate (PET). Geotextiles and Geomembranes 43 (2015) 363e369. DOI: 10.1016/j.geotexmem.2015.04.003

[17] Soltani, Amin; Deng, An; Taheri, Abbas. 2022. Expansion and strength characteristics of an expansive fiber reinforced soil. Geotextiles and geomembranes 46 (2018) 183–189.

[18] Tabassum, T.; Bheemasetti, T.V. (2022): Investigative studies on recycled high-density Polyethylene and Polypropylene pellets for Stabilization of Soils Rich in Kaolinite. Journal of Materials in Civil Engineering. DOI: 10.1061/(ASCE)MT.1943-5533.0004318

Supporting Reading References

a) The Pew Charitable Trusts and Systemiq. (2020). Breaking the Plastic Wave: A Comprehensive Assessment of Pathways Towards Stopping Ocean Plastic Pollution. Disponível em: breakingtheplasticwave_report.pdf (pewtrusts.org).

b) ISO/CD 15270-1.2 – Plastics Guidelines for the recovery and recycling of plastics waste. Part 1: Generales Principles. Status: Under development. Stage: Committee draft (CD) registered [30.00]. Edition: 1. Technical Committee: ISO/TC 61/SC 14. ICS: 13.030.50 83.080.01

c) Klinsky, L.M.G.; K.E. Kaloush, K.E.; Fariga, V.C.; Bardini, V.S.S.; 2018: Performance characteristics of fiber modified hot mix asphalt. Construction and Building Materials 176 (2018) 747–752.ISSN 0950-0618, https://doi.org/10.1016/j.conbuildmat.2018.04.221 DOI: 10.1016/j.conbuildmat.2018.04.221

d) Coelho, R. T. (2005) Contribuição ao estudo da aplicação de materiais alternativos nos compósitos à base de cimento Portland; uso de grão de polipropileno reciclado em substituição aos agregados de concreto. Campinas: FEC/UNICAMP. Dissertação (Mestrado em Engenharia Civil), Faculdade de Engenharia Civil, Arquitetura e Urbanismo, Universidade Estadual de Campinas.

e) D. Gupta and A. Kumar, “Behavior of cement-stabilized fiber-reinforced pond ash, rice husk ash-soil mixtures,” Geotextiles and Geomembranes, vol. 44, no. 3, pp. 466–474, 2016.DOI: 10.1016/j.geotexmem.2015.07.010

f) Plastic Waste Management Institute - PWMI. An introduction to plastic recycling. Tokyo. 2022. Disponível em: plastic_recycling_2022.pdf (pwmi.or.jp).

g) Yadav, J.S.; Tiwari, S.K. “Behavior of cement stabilized treated coir fibre-reinforced clay-pond ash mixtures,” Journal of Building Engineering, vol. 8, pp. 131–140, 2016.DOI: 10.1016/j.jobe.2016.10.006

h) Allan T. Williams, Allan T.; Rangel-Buitrago, Nelson (2022). The past, present, and future of plastic pollution. Elsevier, ScienceDirect: Marine Pollution Bulletin 176 n.113429. DOI: 10.1016/j.marpolbul.2022.113429

i) Ma. Jianmin; Nawarathnaa, Hanwalle M.C.; Hespa, Simon A.M.: About the sustainable use of recycled plastics in flexible asphalt pavements. Journal of Cleaner Production 359 (2022) 132081.