CHAPTER 63

From the plastics manufacturing process to the way to the oceans

https://doi.org/10.56238/alookdevelopv1-063

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ABSTRACT
Plastics are by-products of origin from the petroleum industry, derived from oil and from the extraction of raw materials in the process of refining crude oil. In refineries, oil is fractionated into various types of organic materials, such as naphtha, gasoline, kerosene, and lubricating oils. From the naphtha that is extracted by cracking substances that give rise to conventional plastic. The last step to carry out the production of plastics is polymerization, where polymers arise, where each one differs from the other, arising from this whole process, thermoplastics, and thermosets. Therefore, it is possible to find plastics, ethylene, and propylene, such as polyethylene, polypropylene, polyvinyl chloride, epoxy resin, polyester, phenolic, silicones, and the most diverse types of plastics. Due to the extent and structure of polymers, they can be non-rigid plastics that can have different applicability. Thermosetting plastics, which do not melt by heating, are insoluble and non-recyclable and with differentiated use in various sectors. However, the widespread disorderly disposal of plastics has come to represent one of the biggest ecological problems in the pollution of marine environments, representing 80% of the garbage found in the oceans, being composed mainly of bags and bottles, among other contaminants. The outlook until 2040 shows that the volumes of plastic flowing into the sea could be tripled, with the expectation that it can present an annual quantity calculated between 23 and 37 million tons. Given this reality, studies focused on technologies capable of minimizing the impacts caused by these pollutants on environments have grown exponentially. Thus, the search for alternative measures for the reuse of plastics, being chemical, mechanical or energy recycling one of the solutions for the transformation of plastics, from the areas of biotechnology to civil construction, with the sole objective, to reduce the presence and damage caused by plastic. The highest concentration of garbage may be found in coastal regions and on the seabed. In this context, this review presents the problems of environmental pollution in the oceans caused by rigid plastics and non-rigid plastics, as well as studies directed at the displacement of plastics in the oceans and current technologies to remedy the problem.

Keywords: Synthetic polymers, Microplastic, Pollution, Environmental damage, Seas, Technologies, Remediation of plastics.

1 INTRODUCTION

Plastics are polymeric organic macromolecules, of artificial origin, with very diverse properties, and may present themselves as a rigid and durable material or as quite malleable and easy to combust (CANGEMI et al., 2005).

At the beginning of the twentieth century, new types of materials called plastics were developed, which gradually were increasingly used in the manufacture of the most varied objects. Their versatility is such that, since then, they have been causing changes in consumption, and consequently, in people's lifestyles (PIATTI & RODRIGUES, 2005).

Among the various types of plastic commonly used, polyethylene stands out as being a plastic-type with high production worldwide, a fact that gives it a relatively low cost, in addition to having high durability, which is an advantageous characteristic of this material (DE ASSIS & SANTOS, 2020).

On the other hand, this high durability of polyethylene, and other polymers called plastics, represents a serious ecological problem, given that these polymers are used in the manufacture of various types of packaging and other objects (plastic bags, for example), which are usually discarded after use, accumulating over time in nature, causing significant environmental and visual pollution (FORLIN, FARIA, 2002; COUTINHO et al., 2003; LORENZETT et al., 2013; OZÓRIO et al., 2015).

Not using plastic materials is considered unfeasible by many experts, who claim that the replacement of these with other materials such as paper, wood, glass, and metals, would imply the increase of volume and weight of garbage, and the consequent increase in costs with treatment collection (PIATTI & RODRIGUES, 2005).

In this way, it is essential to develop alternatives that can reconcile the practicality of packaging and sustainable development, allowing consumption and convenience, without compromising the planet's resources (COUTINHO et al, 2004). The current challenge is based on the need to produce knowledge that relates to society, the environment, and the costs/profits of the processes, which requires efforts from the most distinct scientific areas, to eliminate or mitigate environmental problems that may impact future generations, as well as the current one (DE SANTANA SANTOS et al., 2022).

Thus, the objective of this review is to present the path of plastics, showing from their manufacture to their arrival in the oceans, as the technologies used in the market for remediation of this pollutant.

2 A BRIEF HISTORY OF PLASTIC

A plastic word comes from the Greek "*plástikos*". It is used in several areas of human knowledge, presenting a spectrum of meanings, but in general refers to something moldable (PIATTI & RODRIGUES, 2005).

In the early twentieth century, the use of this material grew exponentially due to its versatility, durability, and low cost, being used in the most diverse areas, such as medicine, civil construction and the automobile industry, enabling the replacement of materials such as aluminum, iron, paper, among others (MATTIELLO et al. 2021).

In 1862 the first sample of the first material that would become known as plastic was presented by an Englishman Alexander Parkes, being reproduced through a resin created from cellulose, is very flexible, moldable when heated, and resistant to water. However, due to its high cost, difficulties arose regarding the investment implemented for the production of this material (CARNEIRO, DA SILVA & GUENTHER, 2021). It was only in 1907 that chemist Leo Hendrik Baekeland discovered formaldehyde-phenolic resins, known as "Bakelite", which gave rise to the first synthetic plastic that after molding became hard, rigid, and resistant to heat, inaugurating the so-called "plastic age" (RANGEL-BUITRAGO, NEAL & WILLIAMS, 2022).

A Bakelite was widely used in the last century, being employed in World War II in the manufacture of coins, in the production of some automotive parts of the Ford Motor Company, as well as in the manufacture of housings of electrical equipment. However, due to aesthetic reasons for its little color variation, it was replaced by other polymers (PINTO et al., 2012).

3 COMPOSITION AND CLASSIFICATION OF PLASTICS

Plastic can be defined as a synthetic material obtained through the chemical reaction of polymerization, which gives rise to the so-called polymers, also called long molecular chains (CARNEIRO, DA SILVA & GUENTHER, 2021).

Polymers (the word has Greek origin: poly (many) and mero (parts), are very large molecules formed by the connection of many smaller molecules, called monomers. These molecules, formed by thousands or even millions of atoms, are called macromolecules (PIATTI & RODRIGUES, 2005). Below is represented the monomer of Ethylene and Polyethylene polymer.

Figure 1 – Representation of a monomer and a polymer.

H2C=CH2 (-H2C-CH2-)n

Ethylene Polyethylene

Source: Own authorship.

By physical and chemical characteristics, polymers have interesting properties such as high flexibility, high impact resistance, low processing temperatures, low electrical and thermal conductivity, porosity, and recyclability, among others (DE ASSIS & DOS SANTOS, 2020).

The polymerization of polymers can be carried out by several different techniques and processes, where the most common are: polymerization by addition and polymerization by condensation (PASSATORE, 2013). Polymers can be classified in different ways, depending on the purpose of who classifies them. The most common forms of classification are: from the point of view of chemical structure, the method of preparation, technological characteristics, and mechanical behavior (PASSATORE, 2013).

Polymers can be classified as natural and synthetic. Natural polymers are those that already exist in nature in polymeric form. This is the case with proteins, DNA, starch, cellulose, wool, and silk, among others. Synthetic polymers are those obtained through chemical reactions, that is, they cannot simply be obtained in nature without undergoing some kind of modification in their chemical structure (DE ASSIS & SANTOS, 2020).

Polymers can also be classified according to composition, being considered homopolymers, when formed by a single type of monomer, or copolymers, when consisting of more than one type of monomer. Copolymers can still be subdivided into random, alternate, block, or grafitized (CANEVAROLO JR., 2013). Plastics can be classified according to the mechanical characteristics and availability of the material to melt/melt (Table 1). Under this aspect, plastics can be divided into thermoplastics, thermosets (thermosets), and rubber elastomers (GORNI, 2003).

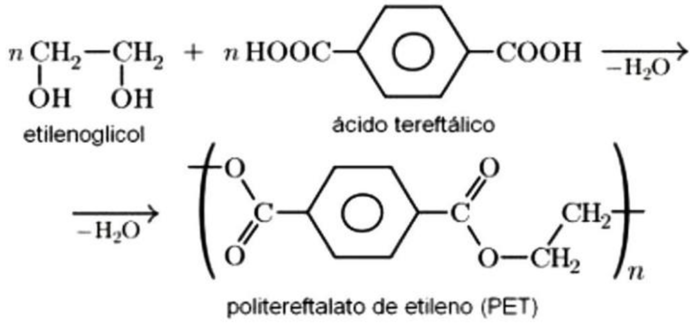
Table 1 – Criteria used to classify polymers

CLASSIFICATION	POLYMER CLASS
Origin of the polymer	Natural
	Synthetic
Number of monomers	Homopolímero
	Copolymer
Method of Preparation of the polymer	Addition polymer
	Condensation polymer
	Modification of another polymer
Fuse and/or solubility of polymers	Thermoplastic
	Termorrígido
Mechanical Behavior of the Polymer	Rubber or elastomer
	Plastic
	Fibre

Source: Own authorship.

Thermoplastics are those that can be melted several times and their recycling is possible, as an example we have PET (Figure 1) (Polyethylene terephthalate), PP (Polypropylene) and PC (Polycarbonate)(GORNI, 2003).

Figure 2 – Esterification reaction in the formation of PET plastic.



Source: Own authorship

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The thermosets, once ready, no longer merge, making their recycling challenging. As an example of these, there are polyester, Bakelite and elastomers, an intermediate class between thermoplastics and thermosets, but they are not fusible, although they have high elasticity (GORNI, 2003). The substances used as raw material in the preparation of plastics are obtained mainly from petroleum and are called monomers (PIATTI & RODRIGUES, 2005). The various types of monomers combine in different ways to make an almost infinite variety of plastics with different chemical properties (PASSATORE, 2013). The fraction from which the monomers are obtained is naphtha, which subjected to a thermal cracking process (heating in the presence of catalysts), gives rise to several substances, among them, ethylene, propylene, butadiene, butene, isobutylene, called basic petrochemicals (PIATTI & RODRIGUES, 2005).

Table 2 – Some types of plastics and their applications.

CLASSIFICATION	EXAMPLE	APPLICATIONS
Thermoplastic	PE - Polyethylene	Plastic bags; film paper
	PP - Polypropylene	Chairs, plastic
	PET - Polyethylene terephthalate	PET Bottles
	PC - Polycarbonate	Awning; roof
	PVC - Polyvinyl chloride	Pipes
Termorrígidos	PU - Polyurethane	Sponges
	EVA - Polyethylene Vinyl Acetate	Rubberized
Elastomers	TPO - Poliolefinas	Diving equipment
	TPE-E - Copoliéster	Automotive springs and antennas
	TPU - Polyurethane thermoplastic elastomer	Skateboard wheels

Source: Own authorship.

4 DECOMPOSITION AND RECYCLING OF PLASTIC

The main consequence of the increase in plastic production is the durability of this material, which causes a long period so that it can decompose in the environment causing a great negative impact due to its accumulation (ABIPLAST, 2020).

In general, the decomposition of plastic is time-consuming and can exceed 500 years depending on its type. Due to this characteristic, there is a high risk of pollution in every environmental sector due to the large amounts of this waste that are generated daily (DIMASSI et al., 2022). The recycling of plastic waste is a task often hampered due to the need to separate waste from its different compositions. Recycling is a set of techniques that aims at the recovery of waste to reuse it in the production cycle from which it came out. Thus, the recycling of plastic waste is a way of using it as opposed to direct disposal in the environment, enabling the reduction of oil use, carbon dioxide emissions and the amounts of solid waste that require disposal (DE ASSIS & DOS SANTOS, 2020).

The burning of plastic waste in incinerators ends up producing pollutants that are released into the atmosphere, greatly affecting air pollution. The figures reveal that around 4.5 million tons of plastic waste are taken to landfills, however, the dumping of these materials in these places is not the "greenest" solution, because its large amount in landfills ends up hindering the decomposition of biodegradable materials, preventing the exchange of liquids and gases between the materials already existing on the site, in addition to residual substances becoming a harmful agent to soil, water and air (DOS SANTOS et al., 2021; LIMA et al., 2022). It is estimated that some variations of plastics take at least 100 years to completely degrade, as described in Table 2. In addition, given the estimated time of decomposition, it is known that the first plastic produced in the world is still in nature (BAIA et al, 2020).

Table 3 – Decomposition time of plastics.

MATERIAL	DECOMPOSITION TIME
PVC	Millennia
Polystyrene	From 500 to 1000 years
Polyethylene	More than 450 years
Polyurethane	From 100 to 400 years
Biodegradable plastics	About 24 months

Source: Own authorship.

The incorrect disposal and low degradation of this material are one of the main factors (ATLAS DO PLÁSTICO, 2020). of pollution, as they are found in various everyday products such as bags, packaging, toys, clothes and even cosmetics. The combination of these two factors becomes a general concern and negatively affects the entire cycle: birth, growth, and recovery (WAN et al., 2019). Due to this, these wastes end up being mostly destined for sewage, seas, rivers, and lakes (TEIXEIRA & TEIXEIRA, 2019). To reduce the problems of pollution by improper disposal, recycling is an option for the proper disposal of a large amount of plastic (ABIPLAST, 2020). Most of the plastic packaging used daily is recyclable, returning to the production chain and ridding the environment of a mass of waste that takes thousands of years to decompose.

Recycling plastic helps reduce the amount of waste generated and ensures better use of the Earth's natural resources. However, the practice of recycling is still very limited, mainly due to the lack of public policies to encourage recycling, as well as the plastic material used, since not all types of plastic are recyclable (BELO et al., 2021). The plastics considered recyclable are water bottles or soft drinks (PET; shampoo bottles and bottles in general; materials for civil construction; bags and flexible packaging; household use packaging; packaging in general and industrial plastics (GORNI, 2003).

5 PLASTIC: A POLLUTING AGENT OF THE OCEANS

In history, the oceans have been pointed out as garbage dumps for human civilizations of all kinds (LEANDRO, DA SILVA & SANTOS, 2021). Plastic waste provided for industrial and domestic activities is a serious problem for aquatic ecosystems (FLORES et al., 2020). It is estimated that between 5 and 13 million tons of plastic are annually dumped into the oceans and, at existing rates, it is pointed out that by 2050 the number of plastics in the oceans will exceed that of fish (DA COSTA, DUARTE & ROCHA-SANTOS, 2019). In 1997, while returning from a trip, oceanographer Charles J. Moore found himself encased in a large "plastic island," which contained plastic of various sizes. The area is calculated at more than 1.3 million square meters of extension, with a depth of 10 meters (PÚBLICO, 2018; ZANELLA, 2013).

The concept of "plastic sea" has been employed to refer to the total amount of plastic in the planet's seas, forming islands of 1.6 million km² (GRECHINSKI, 2020). The "garbage vortex", a region found in the Pacific Ocean, is where 100 million tons of garbage are concentrated, coming mainly from China and less developed countries, such as Indonesia (Table 4) (BAIA et al., 2020; EGGER, SULU-GAMBARI e Lebreton, 2020). Countries that do not have a high level of development tend to stand out for the amount of plastic waste released into the oceans, due to consumption and, consequently, to incorrect disposal (PINHEIRO et al., 2021).

Table 4 – Countries and their respective amounts of garbage-generated plastic

COUNTRY	PLASTIC WASTE GENERATED
USA	70.782.577
China	54.740.663
Brazil	11.355.220
Indonesia	9.885.081
Russia	8.948.132
Germany	8.286.827
Japan	7.146.514
Canada	6.696.763

Source: Adapted from CONCEIÇÃO et al., 2019.

There are different sources for the arrival of plastics in the oceans, each with characteristics of intensity, type and scope. The main sources of this material in the ocean are rivers, whose watersheds are polluted due to the lack of actions to prevent plastics from reaching the environment (HATJE, DA CUNHA & COSTA, 2018).

Research done by the European Parliament in 2018 shows that there are currently 150 million tons of plastic in the oceans. According to data, 49% of plastics found in the sea can be divided into ten main groups of objects made with the material: plastic bottles, straws and cutlery, cups, balloons, cigarette butts, food containers, cotton swabs, intimate hygiene products, candy/snack packaging and plastic bags (EUROPARL, 2018).

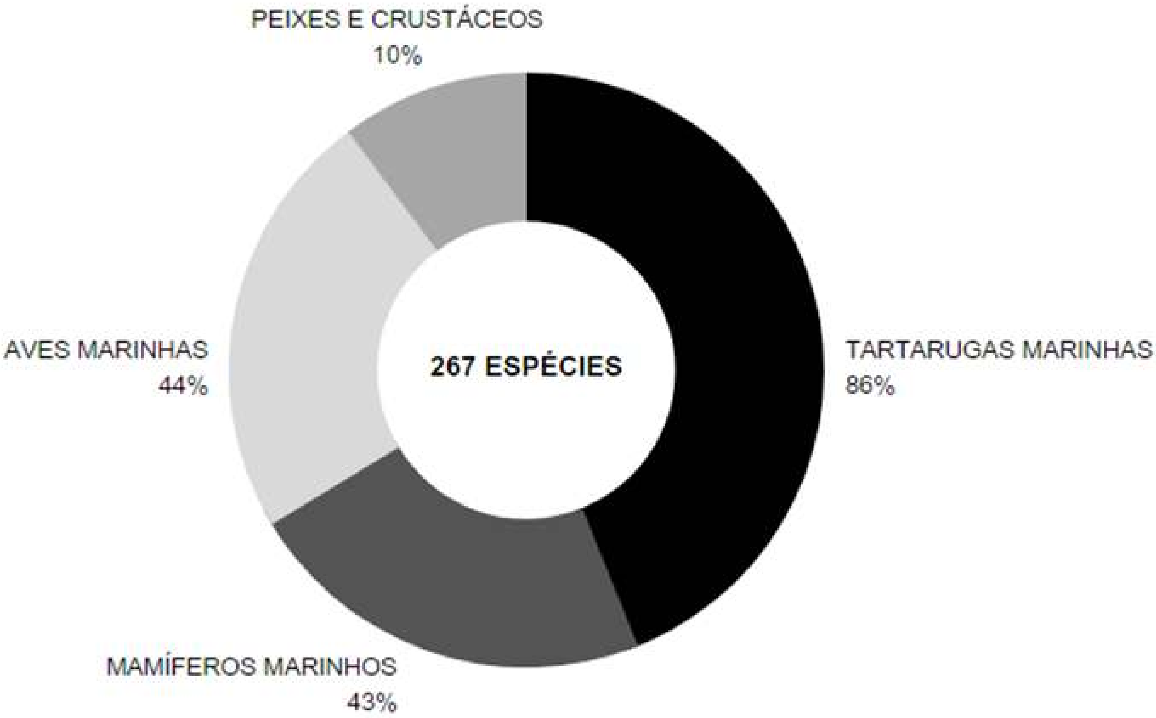
6 ENVIRONMENTAL IMPACTS: PLASTIC AS AN ENEMY OF THE OCEANS

In the marine environment, plastic waste can travel thousands of kilometers in ocean currents, affecting the lives of all the fauna present there. Cases of entanglement incidents have been reported in a wide variety of animals, leading to acute injuries or even death of these (CARNEIRO, DA SILVA & GUENTHER, 2021).

Large volumes of plastic in marine environments pose a serious physical threat to wildlife through ingestion or entanglement of these wastes (SILVA et al., 2019). It is estimated that up to 1 million seabirds and 100,000 mammals can be killed each year due to the large amount of plastic material in the seas (ESCOLA DA AJURIS, 2020).

The occurrence of accidental ingestion by fish, turtles and other animals can harm their reproductive organs or lead to death due to toxic chemicals (SILVA et al., 2019). It is already known that this gigantic amount of plastic is affecting about 267 species of marine animals around the world (ESCOLA DA AJURIS, 2020) (Figure 3).

Figure 3 – Animals affected by plastic pollution in the oceans.



Source: Adapted from SCHOOL OF AJURIS, 2020

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Animals are also affected directly by ingestion of these wastes. Often, small pieces of plastic look like food, such as roe or plankton, and can be easily mistaken and ingested by them, causing disturbances in reproduction and even in the hormone levels of marine species, putting their survival at risk (TRUSTS et al., 2020).

7 EMERGING ISSUES: MICROPLASTICS

The expression microplastic was first created by Thompson et al. (2004), who characterized particles up to 20 μm in size. Plastic particles smaller than 5 millimeters, known as microplastic, found in seas, rivers and oceans are a huge, recurring environmental problem. Microplastics and nano plastics are the plastics with the greatest impact on the environment because, due to their large surface areas, they can absorb components of high toxicity, such as hydrocarbons and heavy metals. It is unquestionable that, once available, these particles are absorbed by organisms and can overcome immune barriers, which can affect organs, tissues and even the functionality of the cell, causing toxic or lethal effects (CAIXETA, CAIXETA & MENEZES FILHO, 2018).

According to their origin they can be classified into primary and secondary. Primary microplastics include materials designed for specific uses in consumer products or industrial applications, which tend to comprise small granules or resin employed as precursors to plastic products (AJITH et al., 2020). On the other hand, secondary microplastics result from chemical (photolysis), physical (erosion), or biological (enzymatic action) degradative processes, typically described for marine and aquatic ecosystems, that affect environmental macroplastics or mesoplastics (LI et al., 2021).

Plastic waste has been observed in terrestrial, freshwater and marine ecosystems around the world. However, one of the most studied ecosystems for plastic pollution is marine environments, which act as a sink for natural and anthropogenic terrestrial entry (AJITH et al., 2020).

In an aquatic environment, it was noted that the main route of the interaction of microplastics with organisms occurs through the ingestion of debris dispersed in water or accumulated in previously contaminated prey, which may result in a series of morphophysiological and reproductive damages to these animals (SILVA et al., 2021).

The effects of microplastic on animals are diverse and can even lead medium-sized animals, such as fish and birds, to death from malnutrition, as they cause a false sense of satiety. Plastic intoxication can also occur by the compounds present in it, such as bisphenol A and phthalate, as well as substances that can be captured, since conventional plastic can easily absorb persistent organic pollutants (POPs) and heavy metals. In addition, it is possible to observe physical effects such as obstruction of the digestive tract (OLIVATTO et al., 2018).

The main and most dangerous effect of microplastics on the oceans is their entry into the food chain, since organisms consume these particles. Later, these same organisms serve as food for other marine species, and these species are food for humans, and in this way, we also ingest microplastics (LÖNNSTEDT, EKLÖV, 2017).

Studies show that those who eat a lot of seafood can ingest 11,000 pieces of microplastic per year and these microplastics absorb all other waste from the environment, such as oil, pesticides and medicines, causing harm to the human being who is consuming this fish (BBC NEWS, 2019).

8 BIODEGRADATION OF NON-RIGID PLASTICS

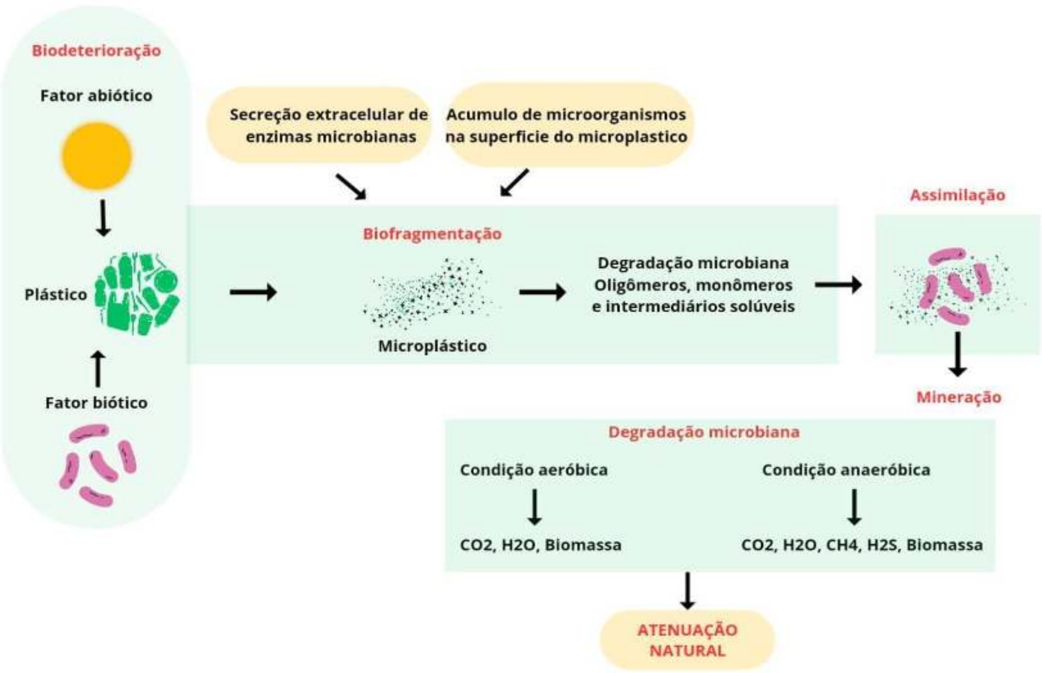
Microorganisms when colonizing microplastics, can use this substrate as a carbon source, as well as can promote vertical gene transfer and antibiotic resistance, the transport of pollutants, and serve as a niche for the growth of other organisms (YUAN et al., 2020).

Bacteria represent the largest group of microorganisms present in nature and it is well known in the literature their ability to form biofilms and degrade pollutants. Studies have revealed that the biodegradation of organic pollutants by pure cultures tends to produce toxic metabolites that can affect microbial growth, however, when there is a consortium of microorganisms these effects are minimized, as these metabolites can be used by other organisms present in the consortium (YUAN et al., 2020).

In addition to bacteria, fungi also have a high potential to adhere to and use plastics as an energy source. Fungi can promote the formation of different chemical bonds in plastics, such as carbonyl, carboxyl, and ester functional groups, decreasing their hydrophobicity (YUAN et al., 2020).

So that the process of biodegradation is effective, microorganisms need to colonize the surfaces of plastics and synthesize various intracellular and extracellular enzymes (ZHOU et al., 2022). Through the colonization and production of enzymes, the biodegradation process occurs following the following steps: biodeterioration, biofragmentation, assimilation and mineralization (ZHOU et al., 2022), as shown in Figure 4.

Figure 4 – Plastic biodegradation process.



Source: Modified from ZHOU et al., 2022.

The biodegradation process can be affected by several factors, among them those related to the growth of the microorganism, surface topography and crystallinity of plastics, water absorption, orientation of polymer chains and reaction temperatures, in addition to the surface-to-volume ratio (MILOLOŽA et al.; 2022).

A full Biodegradation requires microorganisms to use polymers as a source of carbon and energy, however, to accelerate these reactions, some experiments have combined heat treatment with the metabolic activity of bacteria (NADEEM et al., 2021).

9 MARINE BIOPOLYMER-BASED BIOPLASTIC

Bio-based plastics with chemical bonds between CO and CN units are easily accessible and rich in heteroatoms, contributing to the reduction of greenhouse gas emissions and energy consumption during production compared to petroleum-derived raw materials over their lifetime (CYWAR et al., 2022).

The main types of Commercially available bioplastics include plastics based on starch, cellulose, polylactic acid (PLA), polyhydroxyalkanoate (PHA), and biopolyethylene succinate (PBS). According to 2021 market data collected by European Bioplastics it will increase from 2.4 million tons in 2022 to 7.5 million tons in 2026 as an alternative to traditional plastics (CYWAR et al., 2022).

However, the Bioplastics manufactured from terrestrial plant sources such as corn starch, sugarcane, potatoes and banana peels account for less than 1% of total annual plastic production due to their disadvantages such as brittleness, inferior toughness, structural integrity and thermal stability, low strength and high production cost (KATO et al., 2019). Land plant sources have many limitations that make them unsuitable for large-scale bioplastic production. For example, its growth rate depends greatly on weather conditions and seasons, and the cultivation process. In addition to allocating land for bioplastic production it would inevitably compete with food production, endangering food security (PARIKH et al., 2009).

The oceans cover more than 70% of the Earth's surface and serve as habitat for marine organisms. The incredible diversity of marine organisms compared to terrestrial and freshwater species has recently fueled many applications innovative (KATO et al., 2019).

Marine sources have great potential to serve as raw material for the production of biofuels, biomaterials and bioactive compounds. Harnessing marine sources for the development of these technologies can greatly decrease the use of agricultural raw material that could be used as food and mitigate the carbon footprint of fossil fuels (VICKERS et al., 2017).

Seaweed is an important component of the marine ecosystem and comprises macroalgae (seaweed) and microalgae, which share common characteristics and photosynthetic capacity, but are different in size and morphology (NALLAKUKKALA et al., 2022). Seaweed grows in a wide variety of marine environments throughout the year and can achieve high growth without relying on arable land, chemicals, or fertilizers (MALAKA et al., 2020).

The sulfated polysaccharide ulvan, extracted from the cell walls of green algae, is commonly available in Ulva species and consists of rhamnose, xylose, glucuronic acid and iduronic acid monomers. One study was conducted using Ulva compressa, Ulva, Cladophora pellucida, Nemalion helminthoides, Galaxaura rugosa, Gracilaria sp., Padina pavonica and Sargassum vulgare which are commonly found on the coasts of the Eastern Mediterranean and obtained optimal results in the production of these products (LIU et al., 2020).

10 RECYCLING OF PLASTIC IN CONSTRUCTION

The construction material can be obtained from plastic waste in the form of bulk in asphalt and cementitious mixtures, insulators, filler, etc. Despite the great potential application of plastic waste in civil construction, its use and development are still quite limited (ARAÚJO et al., 2016).

The physical degradation of plastic waste evolves through different processes, such as crushing and/or crushing, which are the main stages of mechanical recycling, which will result in the ease of reuse of these products (LEITE & DA SILVA LUCENA, 2022).

One of the main pillars of each nation is the construction industry, which contributes greatly to its economy. Therefore, employing waste materials will significantly improve the sustainability of construction practices and processes. The main objective of the circular economy model is to keep products and their constituent parts at their best levels of efficiency and value throughout the intended life cycle (LEITE & DA SILVA LUCENA, 2022).

A considerable reduction in the disposal of plastic waste in the marine environment will be achieved by employing the innovative sustainable use of plastic waste for construction applications. Therefore, alternative materials can be proposed to meet the great demand of the construction industry. However, the durability and mechanical properties must be by the intended application for the use of polymer residues for construction purposes (ALVES et al., 2022).

In addition, these materials must be sustainable and economical to be replaced by other types of materials. For example, some recycled non-biodegradable waste plastic bags have been used to produce coatings and floors with improved and lower mechanical properties flammability (ALMEIDA et al., 2022).

Studies have shown that plastic bags, known as the main responsible for water and soil pollution, can be converted into highly durable and lightweight products (ALMEIDA et al., 2022).

The research developed uses ring-shaped PET, which was loaded into the concrete to improve its fracture energy, compressive strength, beam flexural strength and tensile strength. It also illustrated that the plastic fibers added to the concrete improved the mechanical behavior of the beams about the resistance to the first crack and load and had almost no effect on the rupture mode. Plastic waste can be employed for internal use and general engineering, in addition to an application for construction purposes (RAMIREZ et al., 2022).

The use of PW as a substitute for aggregate in the construction of base and sub-base for pavements has improved the shear, stiffness and load capacity of the pavement (OZAWA et al., 2023).

Their study showed that the incorporation of PW reduces the stiffness, load capacity and resilience modulus of the mixtures; however, acceptable performance was still achieved. Plastic waste can also be loaded into asphalt mixtures, similar to using plastic waste for cementitious composites as an aggregate (WANG et al., 2022). The incorporation of plastic waste into the asphalt has increased the crack and slippage resistance of the pavement. The use of plastic waste as modifiers in asphalt mixtures significantly improves stiffness and groove strength performance. It is also reported that plastic waste can be employed as a potential substitute for wood, blocks and bricks using molding processing (ABDULLAH 2022).

As an alternative to incorrect disposal of plastics of the type PET, HDPE and PP, are being developed for the conversion of these products into bricks, with physical characteristics, in certain aspects, more economical and resistant than conventional bricks. The most expensive is its production (CHOCKALINGAM et al., 2023) (Table 5).

Table 5 – The types of plastics most found in the civil area and their applications.

Plastic Type	Use in Civil Construction	References
PET	- Used in concrete preparation to improve the reduction of compression fractures -Flexural strength of the beam and tensile strength - Production of bricks with good durability and resistance, with lower gas emissions.	Chockalinga et al., (2023); Barcellos et al., (2022); Leite et al., (2022).
NEED	- Production of bricks with low water absorption capacity, a process that helps reduce problems with infiltration. - Load resistance capacity greater than conventional brick. - The dead weight of the bricks in the structure can be reduced by 55% when compared to a conventional brick.	Adamu et al., (2022); Ahmad et al., (2022); Leite et al., (2022).
PP	- Ability to withstand loads similar to traditional bricks. - The dead weight of the bricks in the structure can be reduced by 55% when compared to a conventional brick.	Zulkernain et al., (2022); Sahani et al., (2022); Leite et al., (2022).

Source: Own authorship.

11 CONCLUSIONS

The problem of plastics in the oceans is becoming increasingly aggravating on the world stage. The durability of this product and the difficulties in the degradation process, as well as the improper disposal, make plastics a villain for planet Earth. Understanding and modifying the polymers and chemical structures that originate the plastics that are marketed and discarded is essential to address the challenges against these pollutants. The microbiota and abiotic factors that encounter difficulties in the natural process in the environment should be considered. Thus, the way to face the challenges with plastics should be to reduce the use of this material, as well as to modify the molecular structures and generate new materials that are less toxic to the environment and probably allow a greater speed of degradation. In this context, the reduction of plastic pollution also requires environmental education and investments in the generation of new technologies. Adopt a conscious consumption of plastics and ensure proper disposal through reverse logistics, as a short-term strategy. And in the long term, new technologies such as chemical recycling, biodegradation and the production of different biocompounds from biodegradable plastics, aim to reduce the life cycle and environmental impacts.

ACKNOWLEDGMENT

The authors thank the granting of Scholarships from FACEPE (Foundation for the Support of Science and Technology of Pernambuco) Process No. IBPG-1175-3.06/22 to Maria Catarina de Farias Caldas and Process No. IBPG-2219-3.06/22 to Júlio César Vasconcelos dos Santos; Scholarship granted by CAPES (Coordination for the Improvement of Higher Education Personnel) Process N088887.828361/2023-00 to Kaio Wêdann de Oliveira, and to the Grant granted by CNPq (National Council for Scientific and Technological Development) Process No. 312241/2022-4 granted to Galba M. Campos-Takaki and the Catholic University of Pernambuco for the provision of academic and laboratory spaces.

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