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REVIEW

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Current Progress and Mechanisms of Microplastic Degradation in the Environment

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Abstract

Plastics, which are beneficial to modern society, have become among the most hazardous pollutants due to excessive use and mismanagement, and their accumulation is causing enormous challenges to ecosystems worldwide. Globally, in 2025, more than 70 million tonnes of plastic waste will enter landfills and oceans, where it slowly degrades and is converted into more hazardous microplastics (MPs) or nanoplastics (NPs). MPs are widely present in the food chain, soil, water, and air and are difficult to degrade in the environment. As these particles can absorb heavy metals and other organic pollutants, they become more hazardous. This review critically examines the mechanisms of various degradation methods, such as chemical degradation, photodegradation, advanced oxidation process, and microbial/enzymatic degradation. These findings will support the formulation/implementation of effective policies and technologies to reduce microplastic contamination, a major environmental threat of the 21st century.

Keywords: Microplastic; Chemical degradation; Photodegradation; Advanced oxidation process; Microbial/enzymatic degradation

Introduction

Plastics, due to their unique properties (lightweight, durability, low price, chemical stability, high tensile strength), are extensively used in multiple sectors such as construction and building materials, electronics and electrical goods, healthcare, agriculture, textile, packaging industries, automotive sector, furniture, sports equipment, household appliances, etc. (Wu et al., 2025; Xiang et al., 2023). It is believed that it is unthinkable to live in the present time without plastic (Tripathi et al., 2025). The data show that global plastic production in 2025 was 516 million tonnes, and the global plastic market, estimated at USD 963.65 billion, is projected to reach USD 1360 billion by 2033 (Grand View Research, 2025). In addition to polymers and oligomers, the plastics also contain several additives such as plasticisers, antioxidants, heat stabilisers, and pigments. Polyester (PES), polyethene (PE), polyethylene terephthalate (PET), polypropylene (PP), polystyrene (PS), polyvinyl chloride (PVC), nylon (polyamide, PA), polyacrylonitrile (PAN), polyvinyl alcohol (PVA), polyurethane (PUR), high-density polyethene (HDPE), polymethyl methacrylate (PMMA), acrylonitrile-butadiene-styrene (ABS), polycarbonate (PC), polyethersulfone (PES), polyvinyl acetate, styrene-butadiene rubber (SBR), low-density polyethylene (LDPE), and polytetrafluoroethylene (PTFE, Teflon) are most commonly and widely used plastic polymers. The contribution of only PE and PP is half of the total global plastic production (Leslie et al., 2022).

Tiny plastic particles/ fragments less than 5 mm in size are termed microplastic particles (MPs). Due to extensive use and improper disposal, MPs are now present in all the compartments of the environment (soil, water (potable, surface, ground, and sewage), oceans, residential areas, air, food web, fish and other seafood, sugar, salt, honey, etc.). Microplastics have also been detected in remote and pristine areas (Antarctica, the Arctic, Mount Everest, and the Mariana Trench) (Aves et al., 2022; Bergmann et al., 2022). Domestic and industrial wastes, fertilisers, personal care products, cosmetics, and synthetic textiles are the major sources of MPs in the environment (Nafea et al., 2024). The accumulation of MPs in soil adversely impacts the terrestrial ecosystems by altering soil structure, microbial activity, and plant growth (Shi et al., 2024; Uwamungu et al., 2022).

Furthermore, several researchers (Abd El-Hack et al., 2025; Dzierzynski et al., 2024) have detected MPs in the tissues of aquatic and terrestrial animals. Tang and Li (2025) and Lang et al. (2024) have detected MPs in human biological samples (sputum, saliva), as well as the placenta, lungs, liver, blood, breast milk, and urine (Osman et al., 2023).

Exposure/bioaccumulation of humans and animals (both aquatic and terrestrial) to MPs induces oxidative stress, cytotoxicity, and altered immune responses, leading to genotoxicity, DNA damage, and gastrointestinal dysfunction. Literature data (Xie et al., 2025; Das, 2023) also indicate that bioaccumulation of MPs adversely affects reproductive health, neurotoxicity, and cardiovascular disorders such as hypertension, atherosclerosis, endothelial dysfunction, and cardiometabolic impairment in mammals.Microplastics pollution, climate change, biodiversity loss and antibiotic resistance are among the biggest threats to humanity in the 21st century (Magalhaes et al., 2025; Zhou et al., 2022). Due to their persistent polymeric nature, MPs take much more time to degrade in the environment.

Therefore, this review aims to compile and analyse the latest global publications proposed by scientists for the degradation/removal of MPs (hazardous pollutants) from the environment.

Remediation/degradation of Microplastics

Microplastic particles (<5mm) are detected in all environmental compartments of the environment, including soil and water bodies (ponds, rivers, marine waters), which are the ultimate sinks of these pollutants. Due to their persistence, mobility, and ecological risks, microplastics along with PFAS and antibiotics are considered the most hazardous persistent organic pollutants of the 21st century. The remediation/degradation of these persistent pollutants in the environment is necessary for society to improve quality of life and human health. The remediation/degradation of microplastics in soil and water occurs by four pathways: physical, chemical, biological and advanced/combined methods. The key mechanisms are given below

Physical degradation Methods

Physical degradation refers to breakdown of microplastic polymers into smaller particles through mechanical processes such as abrasion, crushing, and surface erosion (Ibrahim et al., 2025; Yousafzai et al., 2025). Natural environmental factors such as water movement, UV radiation, exposure, and wind significantly affect the physical degradation of the microplastic polymers. The literature indicates that during physical degradation, the polymers are fragmented but not completely decomposed (Payel et al., 2025; Pfohl et al., 2022; Razavi-Nouri et al., 2020).
Microplastics from water/wastewater can be efficiently removed by combining membrane filtration with the electrocoagulation-electroflotation method, according to the findings of Yuan et al. (2022) and Akarsu et al. (2021). Shen et al. (2022) and Lee and Jung (2022), during their research studies, found that microplastics from wastewater can be removed by the application of an aluminum anode in electrocoagulation. Centrifugation is a tool for the removal of microplastics from wastewater (Pondala and Botsa, 2025; Grause et al., 2022), but this technique is not applicable for very small particles. Membrane filtering methods have also been effectively used to remove microplastic particles from wastewater (Pramanik et al., 2021; Wang et al., 2020). To obtain maximum input, the membrane must be continuously replaced, which enhances the operational cost.

To remove microplastics from water and soil, adsorbents with a strong affinity for microplastics, e.g., activated carbon, biochar, Mg/Zn-modified biochar, and Zn-Al layered double hydroxide, are used (Tang et al., 2021). The microplastic particles are adsorbed on these adsorbents via electrostatic interactions, Van der Waals' force of attraction, hydrogen bonding, and π-π interactions (Wang and Guo, 2020). Recently, sponge and powder-based composite materials that have better adsorption capacity have been used (Xiang et al., 2023; Zhao et al., 2022; Sun et al., 2021).

Chemical degradation

Chemical degradation is the process of breaking down the microplastic particles without involving microbes, through abiotic chemical processes such as hydrolysis, oxidation, and dehalogenation. During chemical degradation, the molecular weight and mechanical integrity of microplastics are weakened, leading to mineralisation. Polymers having a reactive functional group (e.g. carbonyl group) are more easily degraded.

Factors influencing Chemical degradation

Chemical degradation of microplastic polymers is influenced by the following factors:

I. Nature of polymer: Chemical degradation depends on the nature of the polymer (Oh and Stache, 2024; Rizwan and Bilal, 2022). The polymers containing aromatic moieties are not easily degraded (Yousafzai et al., 2025), and short-chain polymers are more easily oxidised (Ibrahim et al., 2025). Microplastic polymers with higher molecular weight resist degradation.

II. Soil organic matter and clay content: High organic matter and clay content provide a larger surface area for faster hydrolytic degradation (Nikhar et al., 2024). The rate of degradation of MPs in soils with high organic matter and clay content is high.

III. Environmental factors: pH and temperature influence the kinetics of microplastic degradation (De-la-Torre et al., 2022). The rate of microplastic degradation at high temperature accelerates as a general rise in temperature enhances the rate of reaction. Low pH accelerates the degradation of high-density polyethene (HDPE). In general, salinity facilitates the microplastic degradation.

IV. Nature of additives: Microplastic degradation also depends on the nature of additives. Those additives that have stronger bonding with the polymer are not easily degraded, while loosely bound additives may facilitate it (Yousafzai et al., 2025).

V. Oxygen Availability: Microplastic particles in the water medium with high values of oxygen content are more easily degraded, as high levels of oxygen content facilitate autoxidation.

VI. Intensity of light: UV light produces reactive species (free radicals) that initiate the degradation of microplastics by polymer chain cleavage.

Chemical degradation methods

1. Thermal degradation/pyrolysis: When the microplastic particles absorb the heat, they disintegrate into monomers; the disintegration is not complete, and takes more time and energy.
2. Thermo-oxidative degradation: In the thermo-oxidative degradation process, the microplastic is exposed to heat and oxygen that cleaves the polymer chain via a chain reaction and produces organic compounds having alcohol or carbonyl groups, which are easily disintegrated into CO_2 and water. This process occurs at low to moderate temperatures in the environment. Thermo-oxidative disintegration generally occurs after photodegradation (Rad et al., 2022; Zhang et al., 2022).
3. Thermocatalytic oxidative degradation of polymers: The transitional metals have variable valence with a large surface area, and act as a catalyst for the thermal degradation of microplastic polymers. These transitional metals generate ROS by reaction with oxygen, cleaving the C-H bond of microplastic polymers by acting as a Fenton's reagent (Zandieh et al., 2024; Hu et al., 2022; Kim et al., 2022) as:

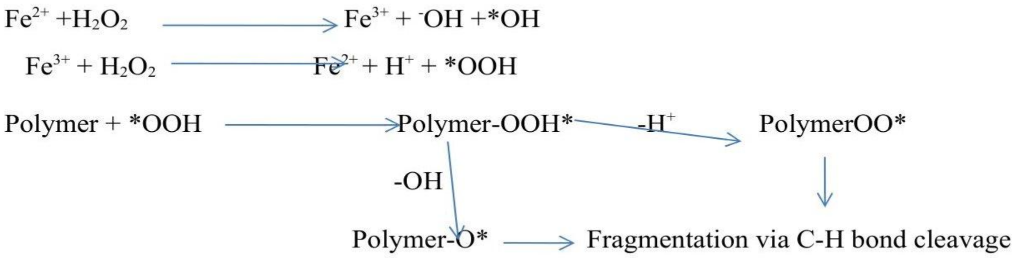

Fig 1. Mechanism of Degradation of polymers by Fenton's reagent

Advanced Oxidation Processes (AOPs) for Microplastic degradation

Advanced oxidation processes are one of the latest effective chemical methods used for microplastic degradation (Oh et al., 2024; Xiang et al., 2023). AOPs degradation follows the three-stage mechanisms: i) oxidation of functional groups present (-OH, >C=O, -COOR, etc.), ii) C-H bond cleavage, and iii) polymer chain disintegration. AOPs include photodegradation, photocatalytic degradation and electrochemical oxidation (Izumiya et al., 2023; Xiang et al., 2023). During electrochemical oxidation, an electric current generates reactive radicals at the anode surface. Studies have shown that polystyrene is degraded by the use of boron-doped diamond as an anode. Miao et al. (2020) have used TiO_2/graphite as a cathode for the degradation of microplastics without producing secondary pollutants. However, due to the formation of uncontrollable intermediate compounds, this method is not widely used.

Hydrolysis

Microplastic polymers containing ester or amide groups, such as PET, polyurethane, PLA, PBS, can be degraded via hydrolysis, i.e. the polymer chains are broken down by the water into water-soluble oligomer or monomer. The efficiency of hydrolysis depends on several factors, including polymer nature, shape and size of polymer, temperature, pH, and/or enzymes present (Zoppas et al., 2023; Silva et al., 2023). In seawater and soil, the hydrolysis process is the major degradation pathway for microplastic polymers. Studies (Lee and Jung, 2022; Yang et al., 2021) have shown that the microplastic polymers PET, PVC, PS, PMMA, PLA, Nylon, and PBT can be degraded easily in the acidic medium.

***Microbial degradation of microplastic*:**

Microbial degradation is one of the most efficient pathways for microplastic degradation in the natural environment, particularly in water and soil. The microbial degradation is a multistep process and degrades microplastics into CO_2, H_2O, and several other non-toxic products. Major groups of microorganisms involved are bacteria, algae, protozoa, fungi and viruses. Bacteria and fungi that are most abundant in nature are widely used for the biological degradation of organic compounds. More than one type of microbes (mixed consortia) may degrade any organic compound more efficiently than a single strain. The rate of microbial degradation generally enhances with time as microbial mutations occur very rapidly.

When microplastics come in contact with microbial cell membranes, the enzymes present in the microbe break down the microplastic into smaller fragments. The degradation mechanism depends upon the type of microplastic and the microbial species involved. Microbial degradation occurs via two main pathways: i) aerobic degradation, which occurs in the presence of oxygen and dominates in soil environments, not in water (as less oxygen is available), ii) anaerobic degradation, which occurs in the absence of oxygen. This type of degradation occurs in water and in soils below the first layer. The microbial population in the proximity of the soil surface is very high due to the presence of materials excreted by the plant roots, so the degradation of the organic compounds is faster in the first layer of the soil. The studies have also noted that bacterial decomposition predominates at $pH > 5.5$, whereas fungal degradation dominates at $pH < 5.5$. Overall, the microbial degradation process involves reactions such as oxidation, reduction, hydrolysis, hydroxylation, and ring cleavage.

Factors influencing the microbial degradation of microplastics

Microbial degradation of microplastics is influenced by plastic properties, microorganisms' performance and external environmental conditions.

I. Physical and Chemical properties of microplastic: Smaller particles have a larger surface-area-to-volume ratio, which provides more space for microbial colonisation and can be easily degraded. Crystalline polymer structure provides a physical barrier to microbes, so the crystalline plastics are degraded more slowly than amorphous structures. Microplastic polymers having heteroatom(s) (e.g., PET, PUR, and PLA) can be more easily degraded in comparison to stable C-C bonds, viz., PE, PP, PS, and PVC. The hydrophobic plastic polymers hinder the attachment of microbes on the surface, which is slowly degraded. Additives such as plasticisers either enhance or retard polymer degradation depending on their toxicity to microbes.

II. Microbial characteristics: The degradation efficiency of microbes depends on the secretion of specific extracellular enzymes such as hydrolases, oxidases, PETases, cutinases, laccases, alkane hydroxylases, which break down the polymers into monomers or CO_2. Studies have shown that the process of degradation is more effective and efficient in the presence of mixed microbial consortia than in a single strain. The degradation process also depends on the capacity of the microbe to develop the plastisphere (microbial biofilm on plastic surface) (Lv et al., 2024).

III. Environmental Factors: The following environmental factors impact both the physical state of microplastics and microbial growth.
a) Temperature: Higher temperatures increase the metabolic activities of microbes and degradation rates, but extreme heat can inhibit or kill the microbes.
b) pH and salinity: Maximum bacterial activity is at neutral pH, while slightly acidic conditions favour fungal activity.
c) Soil organic matter: Higher organic matter in soil enhances the degradation of microplastics through co-metabolism.
d) Soil moisture: Bacterial degradation of microplastics in soil is faster in those soils that have a high level of soil moisture.
e) UV Radiation: Sunlight via UV radiation induces physical cracks in the microplastic, enhances microbial colonization, and increases the rate of degradation.
f) Nutrient Availability: The presence of essential nutrients such as glucose, nitrogen, and phosphorus stimulates microbial growth, which in turn increases the degradation of plastic by consuming it as a carbon source.

Microbial degradation of Polyethylene terephthalate (PET)

PET microbial degradation is an eco- friendly process in which enzymes secreted by microbes convert PET into carbon and energy (Yan et al., 2024; Ibrahim et al., 2025; Gao et al., 2024) as:

Bacterial degradation: Bacterial species such as *Bacillus sp*. and *Ideonella sp*., *Ideonella sakaeiensis* isolated from microbial consortia 46, can degrade PET. The enzymes involved are PETase, MHETase, LCC, ThermoPETase, and BurPL (Jiang et al., 2025):

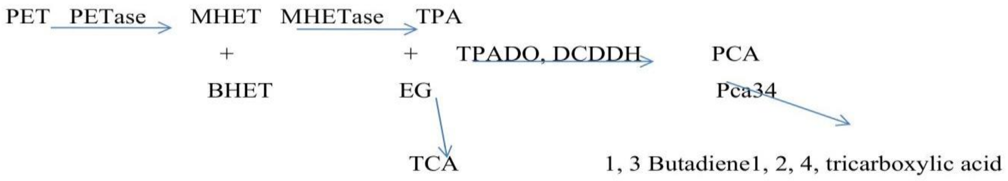

Fig. 2. Mechanisms of bacterial degradation of PET

(Abbreviations: MHET- Mono-(hydroxyethyl) terephthalate; BHET- Bis-hdroxyethyl terephthalate; TPA-terphthalic acid; EG-ethylene glycol; TPADO-TPAdioxygenase; DCDDH-1, 2-hydroxy 3,5 cyclohexadiene-1,4diethyl acetate dehydrogenase; PCA-Primary catechin acid; PCA34- PCA3,4 dioxygenase)

Fungal degradation**:** Fungal species such as *Aspergillus sp.*, *Penicillium Sp*, *Fusarium solani*, and *Themomyces languginosus* can degrade the PET in soil and water. The enzymes that break down are lipase and cutinase. The proposed degradation mechanism is as follows**:**

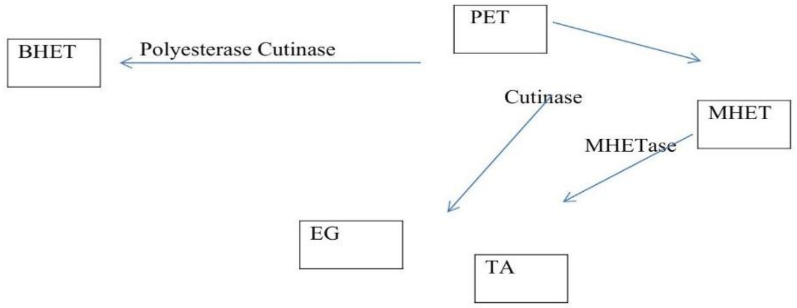

Fig. 3. Mechanisms of fungal degradation of PET

Microbial degradation of Polyethene (PE)

Polyethene, hydrophobic in nature, is the most utilized plastic with low to high molecular weight resistant to microbial degradation; due to the presence of impurities, it undergoes bacterial and fungal degradation (Okal et al., 2025; Wang et al., 2025; Wang et al., 2024; Zhai et al., 2023; Yao et al., 2022; Spina et al., 2021)

Bacterial degradation: Low-density polyethene (LDPE) is degraded by the enzymes laccase, alkane hydroxylase, oxygenases secreted by *Bacillus cereus* and *Pseudomonas aeruginosa*, while extracellular enzymes, lipases and laccases, secreted by the bacteria *Bacillus species*, *Comamonas testosterone*, *Brevibacillus parabrevis*, *Microbacterium barkeri SH20*, and *Achromobacter xylosoxidans* degrade the high-density polyethene (HDPE).

Fungal degradation: Fungal species such as *Zalerion maritimum, Aspergillus niger, Penicillium sp., Purpureocillum lilacinum, and Humboldtia brunonis* produce enzymes, such as peroxidase, laccase, and oxygenase, that facilitates the degradation of PE.

The Mechanism of PE (LDPE & HDPE) degradation is as follows:

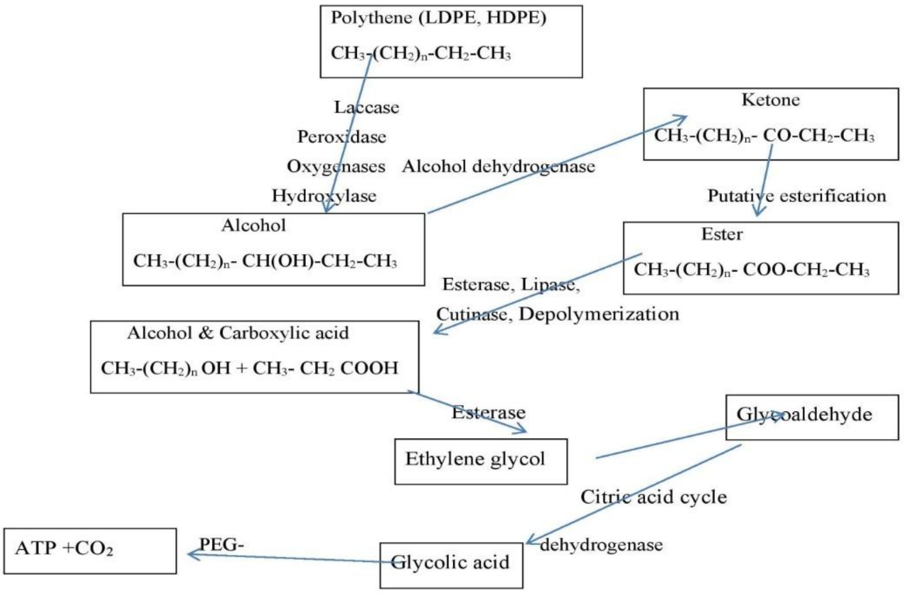

Fig. 4. Mechanisms of microbial degradation of LDPE and HDPE

Microbial degradation of Polyvinyl chloride (PVC)

The global production of PVC in 2025 was approximately 54 million tonnes, accounting for approximately 16% of total plastic production. Microbial degradation occurs via dechlorination, oxidation, depolymerisation, and dehydration mediated by the microbial enzymes (Andleeb et al., 2025; Hatwar and Qureshi, 2025; Zhang et al., 2022).

Bacterial degradation: Bacteria, *Klebsiella sp. EMBL-1*, *Pseudomonas citronellolis*, degrade PVC, using enzymes catalase, dehalogenase, laccase, enolase, dehydrogenase, and oxygenase.

Fungal degradation: Fungi such as *Aspergillus niger*, *Phanerochaete chrysosporium*, *Pleurotus sp., and Polyporus versicolor* secrete manganese peroxidase, lignin peroxidase, and laccase enzymes, which facilitate dechlorination, oxidation, and depolymerisation of PVC, and after breaking the chain, oxidise to CO_2.

The degradation Mechanism is as follows:

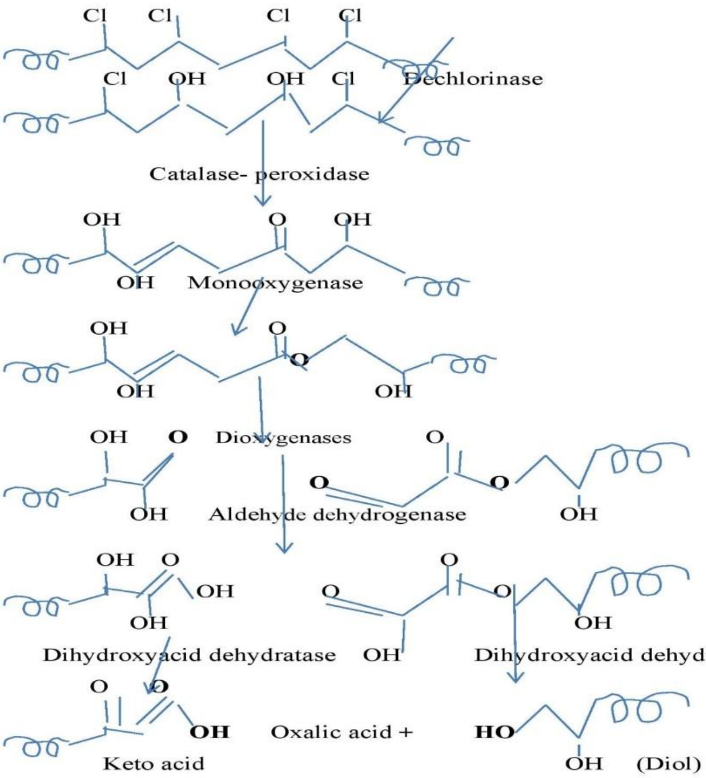

Fig.5. Mechanisms of microbial degradation of PVC

Microbial degradation of Polyurethane (PU)

The polyurethane polymers are step-growth polymers and contain the carbamate (–NHCOO-) bonds widely used in rigid and flexible foams and in the biomedical field. Global annual production of PU polymers in 2025 was approximately 25 million tonnes. The enzymes involved in the degradation of PU polymers are polyesterase, peroxidase, lipase, polyurethanase, urease, and cutinase.

Bacterial degradation: Bacteria isolated from soil, plastic waste soil, landfill, deep sea, foam waste dumpsite, such as *Bacillus sp.*, *Pseudomonas aeruginosa, and Staphylococcus xylosus*, cleave the ester and polyurethane bonds via hydrolysis and convert into fatty acids with the help of extracellular enzymes (Jiang et al., 2024; Liu et al., 2024; Salgado et al., 2024; Ji et al., 2024; Hao et al., 2023).

Fungal degradation: *Pseudomonas aeruginosa, Aspergillus niger, Phanerochaete chrysosporium, Penicillium spp., Aspergillus versicolor* fungi isolated from sewage soil, landfill, foam waste degrade the polyurethane by secreting extracellular enzymes, esterase, protease, polyurethanase (Zhu et al., 2025; Rajan et al., 2024; Xu et al., 2024; Liu et al., 2023). The degradation Mechanism is as follows:

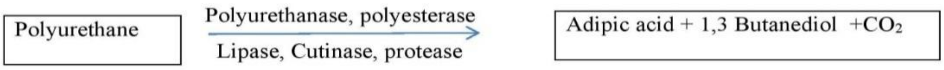

Fig. 6. Mechanism of microbial degradation of PU

Microbial degradation of Polystyrene (PS)

In 2025, the global production of polystyrene, widely used in insulation, packaging and consumer goods (plastic cups, egg cartons, and cosmetic jars), was approximately 16 million tonnes. Both bacteria and fungi can degrade the PS by secreting enzymes, viz., styrene dioxygenase, styrene monooxygenase, laccase, esterase, lipases, dehydrogenases, aldolases, catechol dioxygenases and oxide isomerases (Xiang et al., 2023). The bacteria

Pseudomonas putida, Rhodococcus ruber, Bacillus cereus, and Exiguobacterium sp (Dong et al., 2024; Park et al., 2023) and fungi *Phanerochaete chrysosporium, Aspergillus niger*, *and Aspergillus flavus* (Shereen et al., 2025; Zhang et al., 2022) can secrete the polystyrene-breaking enzymes. Mechanism of degradation is as:

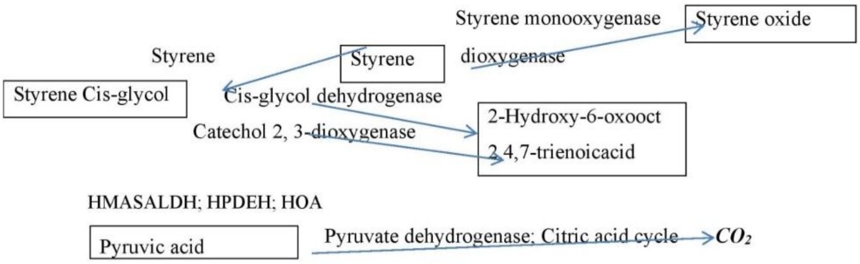

Fig. 7. Mechanism of microbial degradation of PS

Microbial degradation of Polypropylene (PP)

The annual production of polypropylene, a thermoplastic, in 2025 was 94 million tonnes and is expected to cross 100 million tonnes in 2026. The PP is used in packaging, automotive, and medical sectors. Polypropylene dominates the packaging market (>45%). Literature survey denotes that bacterial strain *Bacillus sp., Rhodococcus sp., Pseudomonas sp.*, and fungal strain *Aspergillus fumigatus and Alternaria* sp. can degrade polypropylene significantly. The enzymes involved in degradation are peroxidase, esterase, lipase, cutinase, alcohol dehydrogenase, aldehyde dehydrogenase, and depolymerase (Choonut et al., 2025; Sutkar and Dhulup, 2025; Anggiani et al., 2024). Mechanism of degradation is as:

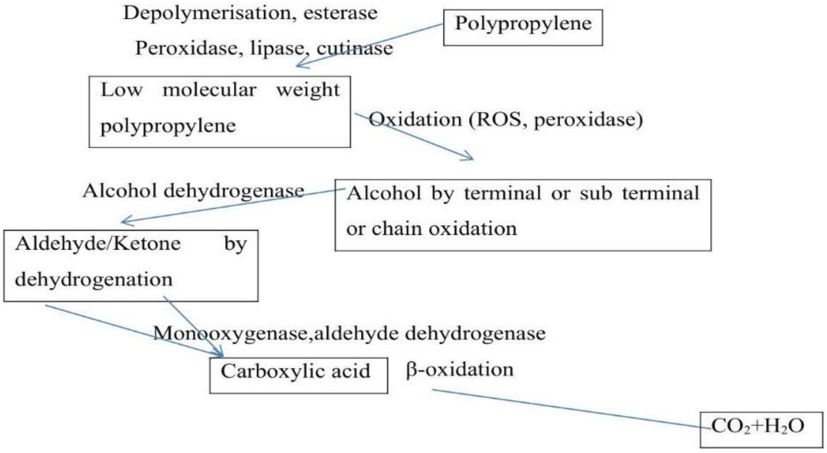

Fig. 8. Mechanism of microbial degradation of PP

Microbial degradation of acrylic polymers

The annual global production of acrylic polymers, which include polyacrylic acid, polyacrylonitrile, polyacrylamide, and polymethyl methylacrylate, is approximately 10 metric tonnes. The literature data denote that the microorganisms *Pseudomonas chlororaphis, Corynebacterium sp., Acinetobacter*, and *Aspergillus niger, Microbacterium sp., Phanerochaete chrysosporium* have the capability to break down acrylic polymers (Supreetha et al., 2025; Gaytan et al., 2021). Nitrilase enzyme converts nitrile polymer into amide, and enzyme amidase converts the acrylamide into acrylate. Acrylate undergoes α or β-oxidation with the help of enzymes monooxygenase, oxidase, and dehydrogenase to form non-toxic low-molecular-weight compounds. The mechanism of degradation is given in Fig. 9.

Photodegradation of Microplastic

Photodegradation refers to chemical structural changes in the plastic polymers, i.e. molecular chain break by sunlight. The energy required for photodegradation is approximately 400-450 kJ/mole, corresponding to wavelengths of 250-300nm. The degradation of microplastics by sunlight may occur on the surface of soil, in water and in the atmosphere. Microplastics having chromophore group(s) (often from additives) degrade more rapidly as chromophore groups absorb light more efficiently. Degradation of microplastics in soil is faster than in water due to the presence of soil organic matter (such as humic and fulvic acid), pigments (i.e., chlorophyll, xanthone) and plant metabolites.

During photochemical reactions homolytic bond cleavage occurs, with the generation of free radicals such as $*CH_3$, $*OH$, $*O^{2-}$, $*R$, $RO*$ etc.

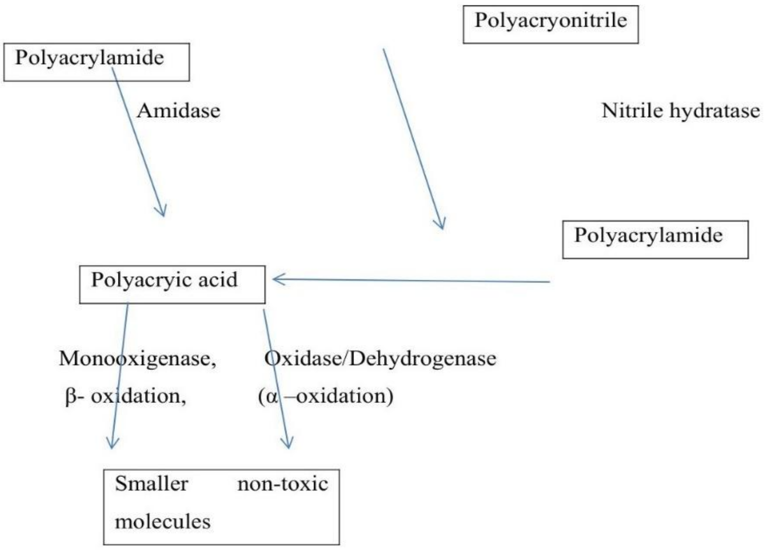

Fig. 9. Mechanism of microbial degradation of Polyacrylic polymers

Factors influencing the photodegradation of microplastics

Photodegradation of microplastics depends on polymer type, surface area of microplastic, polymer structure, light intensity, catalyst present and external conditions such as pH, temperature, organic matter, etc.

I. Physico-chemical properties of microplastics: The chemical structure of the polymer plays a significant role in degradation. Microplastic polymers that are aliphatic in nature, such as polyethene, polypropylene, and polyvinyl chloride, are more easily photodegraded than aromatic polymers (e.g. polystyrene). The data have also shown that the presence of a functional group in the microplastic polymers facilitates their photodegradation, while the rate of photodegradation is slower in crystalline polymers (Wu et al., 2025; Yin, 2025). Particles with higher surface area-to-volume are more easily degraded (Llorente-García et al., 2020).

II. Light characteristics**:** Light intensity is one of the major factors that impact the photodegradation of MPs. Higher light intensity increases the number of photons per unit time, which promotes the probability of free radical generation that results in an increase in the rate of photodegradation of MPs (Arrendo-Navarro et al., 2026; Yin, 2025; Bloh, 2021; Chen et al., 2020). UV-B radiation is more effective than UV-A radiation for MPs degradation. Yin (2025), during their studies, found that the rate of polystyrene MP degradation in the presence of UV-A radiation is 40% lesser than that of UV-B radiation.

III. Environmental factors**:** Environmental factors such as temperature, pH, and humidity/water content, and oxygen availability impact MPs' degradation.
(a) Temperature**:** Temperature significantly impacts the photodegradation of MPs. Increased temperature enhances the thermal molecular motion of molecules, accelerating the free radical generation and diffusion, resulting in acceleration of the photodegradation process. The optimal temperature for photolysis of MP is between 20-80°C (Romero-Moran et al., 2021; Lee et al., 2020). The activity of the photocatalyst and degradation efficiency is also impacted by temperature.
b) pH**:** The degradation of MP is also impacted by pH. Microplastic polymers are better degraded at particular pH. Photocatalyst activities are also impacted by the pH of the medium (Wu et al., 2025; Ariza-Tarazona et al., 2020).
c) Oxygen availability: Higher oxygen levels enhance the photodegradation of MPs. The degradation in surface water where oxygen is in high amounts is faster than in lower-oxygen areas, i.e. deep sea, as photooxidation is one of the major pathways of degradation.
d) Humidity/Water: Moisture/humidity enhances the penetration depth of ultraviolet rays and promotes the formation of hydroxyl free radicals (*OH), which degrade indirectly.
e) Organic matter: The organic matter (DOM) and nutrients present in aquatic environments or in soil form hybrid particles by interacting with the plastic surface, which may either accelerate or inhibit the degradation rate.

IV. Photocatalysts and Additives: Those substances that have the capability to absorb photons undergo charge separation and charge transfer, acting as a photocatalyst. These substances enhanced the rate of photoreaction. The literature data denote that composite catalysts of metals, non-metals and various other substances can more efficiently degrade the microplastic polymers (Wu et al., 2025; Li et al., 2023). Monocatalyst TiO_2, ZnO, CuO and composite material Ag/TiO_2 RGO, magnetic $CuFe_2O_4$, Cu_2O/CuO, GO-ZnO, C, and N-TiO_2 are some of the common examples of photocatalysts (He et al., 2023; Jiang et al., 2023; Tan et al., 2023; Qin et al., 2022).

Photodegradation Mechanisms

Photodegradation of microplastic polymers is a chain reaction, involving three major steps: initiation, propagation, and termination. At the initiation step, the chromophore, impurities or catalyst absorbs a photon and breaks the polymer chain via free radical formation (homolytic bond cleavage). In the propagation step, the free radical formed reacts with oxygen to form peroxy radicals, initiating autoxidation reactions. Termination of the reaction occurs when any two free radicals combine with each other to form a stable product (s) (Kinyua et al., 2023).

Mechanism of degradation of Polyethene (PE): PE undergo photolytic degradation (Lu et al., 2025; Ling et al., 2023; Wang et al., 2023; Yao et al., 2022; Majhi, 2021)

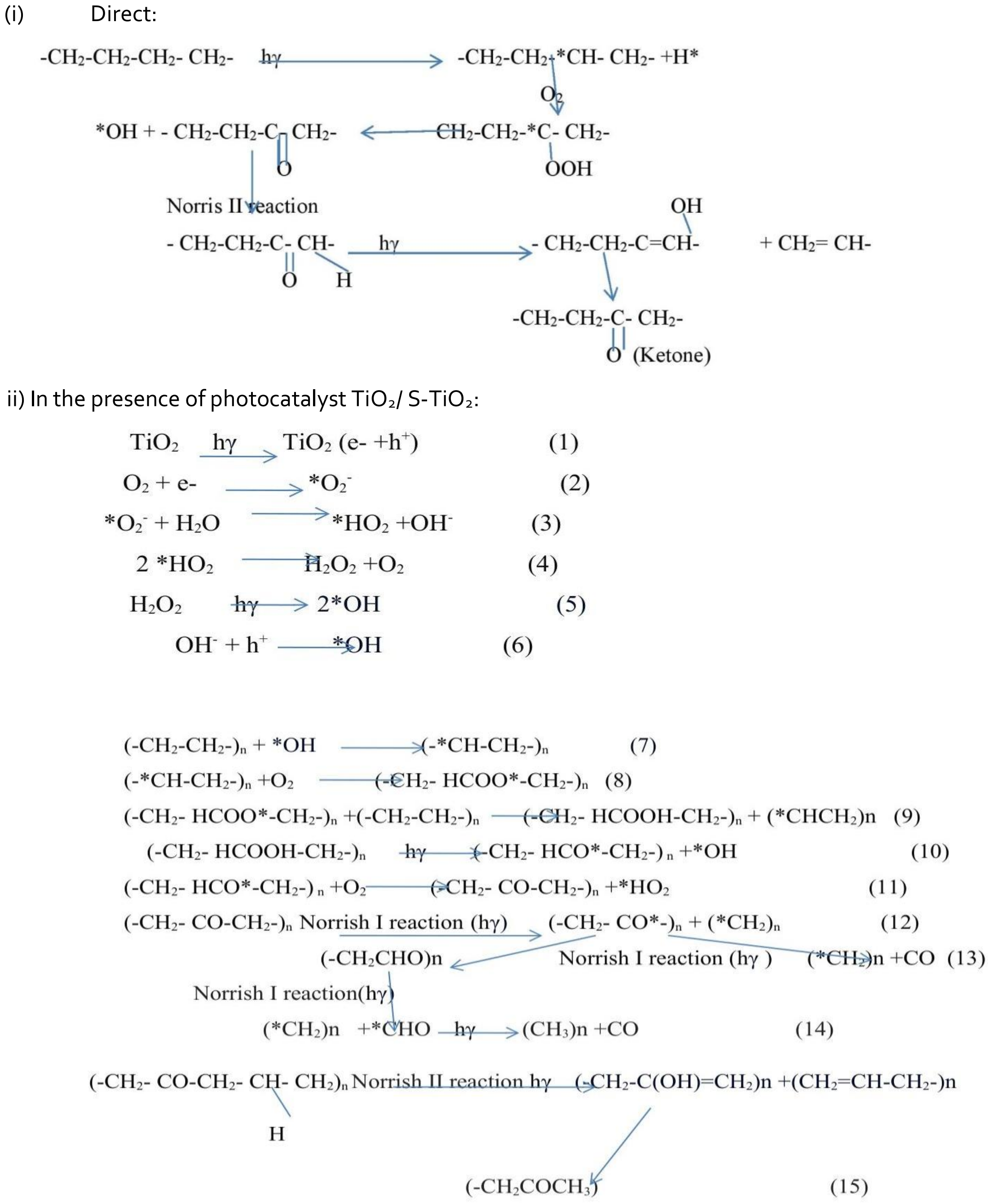

Fig. 10. Photodegradation mechanism of PE

Mechanism of degradation of Polypropylene (PP)

PP undergoes degradation (Liu et al., 2022) as per Fig. 11.

Mechanism of degradation of Polyethylene terephthalate (PET)

In the presence of UV light and humidity, the PET, undergoes photolytic degradation via Norrish type I and type II reactions (Sun et al., 2025; Rostanpour et al., 2024; Jiang et al., 2024). Norrish reactions excite the carbonyl group (>C=O). In Norrish I type reactions, the C-C bond alpha to the carbonyl (>C=O) group is cleaved to form radicals, while in Norrish II reactions, a hydrogen atom from the gamma carbon atom is transferred to the carbonyl oxygen with cyclisation. Mechanism is as per Fig. 12.

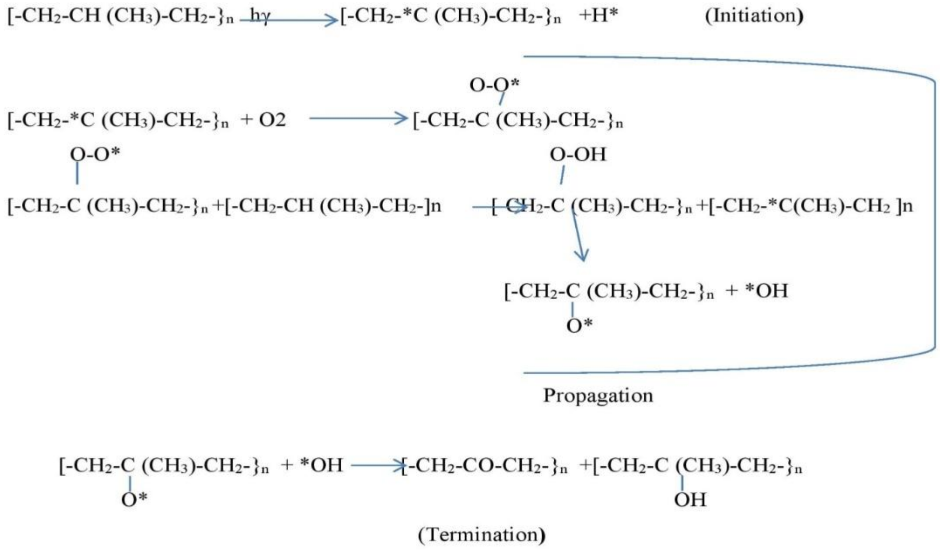

Fig. 11. Photodegradation mechanism of PP

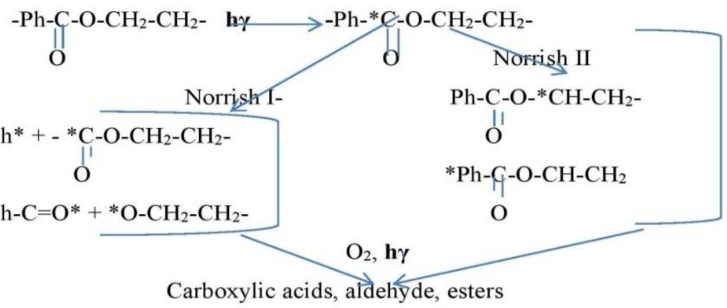

Fig. 12. Photodegradation mechanism of PET

Mechanism of degradation of Polystyrene (PS)

The major component of global plastic waste is PS, as it is a single-use plastic, due to the presence of the aromatic benzene ring, which cannot be easily degraded. Photodegradation of PS occurs by UV light in the presence of a catalyst (TiO_2; nanostructured bismuth carbonate) (Kilinc et al., 2025; He et al., 2023).

Mechanism is as:

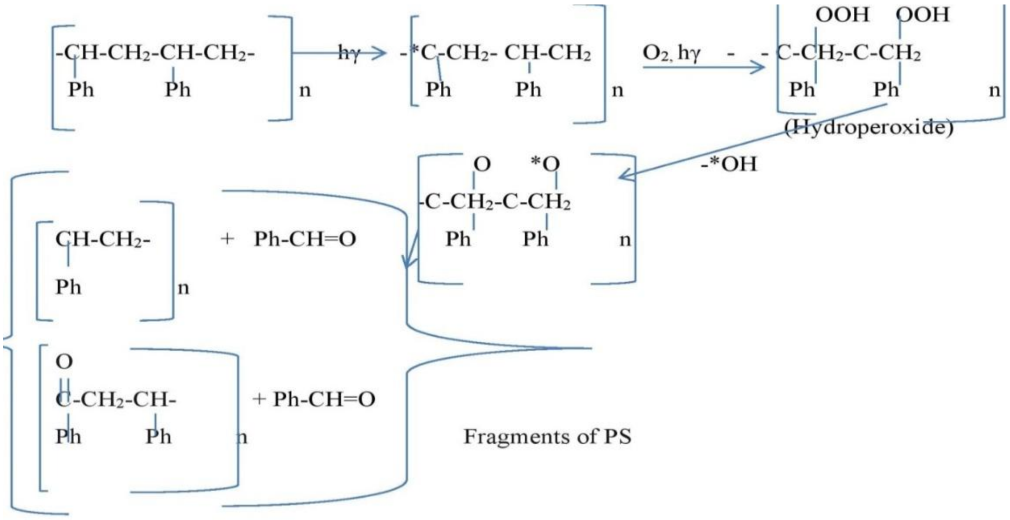

Fig. 13. Photodegradation mechanism of PS

Mechanism of degradation of Polyvinyl chloride (PVC)

PVC degradation is a chain reaction that happens in the presence of UV light; during the process, dechlorination and oxidation occur with the formation of free radicals. The reaction occurs as (Pok et al., 2025; Ding et al., 2022):

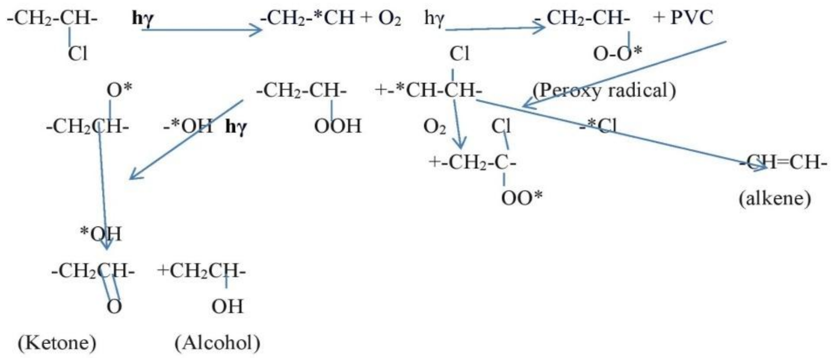

Fig. 14. Photodegradation mechanism of PVC

Photodegradation of acrylic polymers

During photodegradation of acrylic polymers, chromophores present in the polymer or from impurities absorb the photon (UV region) to form free radicals, which are converted into peroxyl radicals by reaction with oxygen, which breaks the chain to form carbonyl, alcohol or esters. (Huang et al., 2024; Lee et al., 2023)

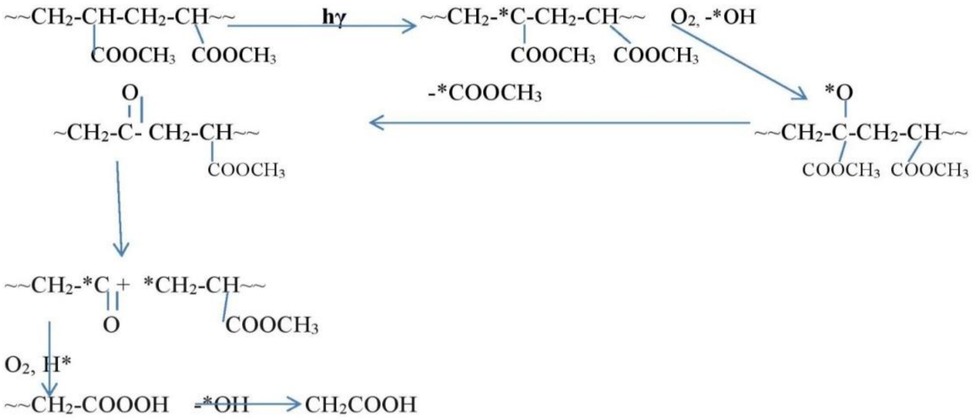

Fig. 15. Photodegradation mechanism of acrylic polymers

Current Gaps in Microplastic Degradation

- Microplastics in most of the existing degradation techniques are not completely mineralised.
- The microbial degradation is generally a very slow process.
- During degradation, some intermediates formed are toxic and compounds used as plasticisers and stabilisers are released, which pose environmental and health risks.
- Microbial/enzymatic degradation methods that are very promising in laboratory experiments often are not so effective when applied at an industrial scale or in natural environments.

Future Strategies and Emerging Technologies

- Future research studies must be focused on achieving efficient biodegradation of MPs under environmental conditions.
- Identification and development of more effective microbial strains are essential.
- Mixed microbial consortia must be synthesised using microbes that produce enzymes PETase, laccases, MHERase, as they are more efficient than a single strain.
- Plastic-consuming genetically modified organisms must be developed.
- Research should focus on the development of improved catalysts to enhance advanced oxidation processes.
- Research studies must explore and/or identify the plastic-eating insects, e.g. Tenebrio molitor.
- Instead of fossil fuel plastics, biodegradable alternatives must be developed.
- To enhance the efficiency and effectiveness of microplastic degradation, the microbial degradation process and the photocatalytic process must be integrated, and cost-effectiveness must be taken care of for wide implementation.

Conclusions

- Microbial degradation is the major pathway for the degradation of microplastic particles, followed by photolysis and chemical degradation.

- Microbial degradation can occur under both aerobic and anaerobic conditions and is carried out by bacterial, fungal or mixed microbial consortia.
- In neutral and slightly alkaline conditions (pH>5.5), bacterial degradation predominates, while in acidic medium (pH <5.5), fungal degradation dominates in water or soil.
- Bacterial genera *Bacillus sp., Ideonella sp., Pseudomonas sp., Comamonas testosterone, Brevibacillus parabrevis, Microbacterium barkeri SH20, Achromobacter xylosoxidans*, and fungal genera *Aspergillus sp., Penicillium Sp, Fusarium solani, Themomyces languginosus, Zalerion maritimum, Purpureocillum lilacinum, Humboldtia brunonis, Microbacterium sp*., and *Phanerochaete chrysosporium* are the most important microbes that can degrade MPs.
- Degradation of MPs is influenced by physicochemical properties of microplastics, environmental factors such as pH, temperature, organic matter, and oxygen availability.
- Photodegradation occurs through a chain reaction involving three major steps: initiation, propagation, and termination. The initiation step requires energy of approximately 400 kJ/mole corresponding to UV wavelengths of 250-300nm. The photolysis is influenced by the intensity of light and exposure time. Photocatalysts and additives present in MPs also impact photolysis.
- During photochemical reactions, free radicals such as $*CH_3$, $*OH$, $*O_2^-$, R, RO, etc. are formed.
- Oxidation, hydrolysis, bond and chain cleavage are the major reactions of MPs' degradation.
- Advanced oxidation processes (AOPs) are among the most effective modern chemical methods for MPs degradation. AOPs degradation follows the three-stage mechanisms: i) oxidation of functional groups present (-OH, >C=O; -COOR, etc.), ii) C-H bond cleavage, and iii) polymer chain disintegration.

Declaration

No original data have been used in this review; all information is accessed from published work.

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