Biodegradable and Compostable Polymer Materials

A brief explanation from the Bio-based and Biodegradable Industries Association – April 2021

Life on Earth depends on organic carbon, the key building block for the many natural macromolecules crucial to life. Nature has evolved a process for recycling this organic carbon so that at the end of an organism's life the natural polymers are broken down and the carbon can be re-incorporated into new living structures.

This process is biodegradation, which can take place in the presence of oxygen (aerobic) or in its absence (anaerobic). The rate at which a natural material will biodegrade will depend on the material itself but also its environment and can vary widely – nature can take its time. Both a tree and a park bench made from trees will biodegrade. But when? Though biodegradable, both the tree and the park bench will last for decades. Managed biodegradability only has intrinsic value if you can ensure that the final state of absorption into the environment will take place in a useful and predictable timeframe.

Biodegradation is typically carried out by bacteria, fungi and other micro-organisms, all of which play an important role in maintaining and enriching soil fertility.

Biodegradable, but when?

Utilising biodegradability in polymer materials

Biodegradation of material in the context of plastics has been defined as "the conversion of all its organic constituents to carbon dioxide, new microbial biomass and mineral salts under aerobic conditions, or to carbon dioxide, methane, new microbial mass and mineral salts under anaerobic conditions." [1]

Bioplastic materials are now available that utilise biodegradability as a property that can deliver value when they are used in certain appropriate applications. These materials are typically based on a polymer or a blend of polymers that are themselves intrinsically biodegradable. There are two key characteristics here that determine whether and where the biodegradability of a bioplastic is useful:

1. To be of practical value the rate of biodegradation has to be appropriate to the timescale of the end use/application involved.

2. The environment in which the bioplastic finds itself at the end of life. Sometimes bioplastics will break down in certain conditions but not in others (e.g., a material might biodegrade in compost or soil, but not in a marine environment). A few biopolymers will biodegrade under a wider range of environments, for example polyhydroxy alkanoates (PHAs), but these are not a panacea - property and processing characteristics can still restrict potential end uses.

These requirements mean that the end-of-life value in biodegradable plastics is best garnered in managed environments that ensure that appropriate conditions are maintained to deliver full biodegradation. *It is important to recognise that a claim that a plastic material is biodegradable is of little value unless it qualified by reference to the relevant environment(s) and the time taken to completely biodegrade.* Marketing a material as "biodegradable" without this additional information is not helpful, and indeed can convey a misleading impression to the consumer.

To ensure that a biodegradable plastic offers real environmental benefits, standards and protocols have been developed that define methodologies intended to reflect realistically a range of end-of-life scenarios. These include composting, anaerobic digestion, and breakdown in soil.

Composting

Aerobic industrial composting (IC) of bioplastics has been widely adopted, with well-established test standards and certification schemes across both Europe and North America[2,3]. These tests are designed to reflect real-life composting conditions and timescales and have achieved a high level of credibility. They involve testing biodegradability, disintegration, and ecotoxicity.

The use of biodegradable and compostable caddy bags for collecting food waste is a prime example, where using a bioplastic greatly facilitates handling and hygiene. It will leverage the UK's efforts to collect and usefully divert the very large amount of food waste currently going to landfill and incineration, as the bags themselves will compost alongside the food waste. The large and real benefit here is that the resulting compost can be used to improve soil quality without plastic contamination.

Inseparable mixed materials such as multi-layer flexible packaging are often not recyclable. Food-contaminated flexible packaging, teabags and coffee pods are all examples. These products can be formulated using compostable materials, so that their organic carbon content can be returned to the carbon cycle, with benefit to soil improvement.

According to One Green Planet, home composting is one of the greenest things you can do as a homeowner. An increasing trend is for relevant products such as food and garden waste bags and teabags be formulated for use in home composting (HC). Home composting is a gardening activity, less controlled, slower, and with lower temperatures, when compared to IC. Suitable test protocols and criteria have been developed in Europe and elsewhere, again with accompanying certification schemes, to reflect the differing conditions and timescales in HC[4].

Composting standards require a minimum biodegradation level in the biopolymer material: 90% conversion of organic carbon to carbon dioxide. This carbon is returned to the atmosphere, where it can be photosynthesised by plants and thus be recycled repeatedly around Nature's carbon cycle – an organic circular economy in action. In the course of being broken down in the composting process bioplastics contribute energy to help power the process and behave in a manner analogous to that of naturally occurring polymers like cellulose. Compostable packaging, whether based on cellulose-fibres (paper, cardboard) or on biodegradable plastics, behaves similarly to other composting feedstock and contributes to the composting process and to the production of good quality compost.

The question is often asked, what happens to the remainder of the carbon? The answer is that the residual carbon has been assimilated into the biomass of the micro-organisms breaking down the polymers – carbon conversion is complete, and no microplastic residue is present[5].

Anaerobic digestion (AD)

Anaerobic digestion (AD) can be viewed as a complementary technology to aerobic composting, and again can be used for handling food waste, alongside animal manure, fats, oils and greases, sewage sludge and other bio wastes. For AD, biodegradation takes place in the absence of oxygen, and produces a range of outputs. Biogas is a mixture of methane (~60%) and carbon dioxide (~40%). This is typically captured and burnt to power the digestion process itself, but also to provide heat and power which can be utilised locally or fed into the grid in the case of electricity. A residue of digestate results from the process, rich in nutrients, which (when carefully managed) can be used for soil improvement or other applications.

In practice there is a range of different methods in use for carrying out AD involving dry or wet conditions, and lower (mesophilic) and higher (thermophilic) temperatures. Compostable caddy bags can once more facilitate convenient and hygienic food waste collection. In some plants they can be pulped into the digester with the biowaste and composted afterwards. In other plants they can be removed prior to the process for aerobic composting. In dry AD they can be treated along with other biowastes. Thus, AD recovers useful energy from biowaste, and at the same time produces nutrient rich digestate for spreading on the land.

The standard BS/EN 13432, Packaging : requirements for packaging recoverable through composting and biodegradation covers AD as well as industrial composting and there is also a US ASTM standard for anaerobic digestion testing[2,6]. Publicly available specifications governing compost and digestate quality have been published by the BSI[7].

Soil biodegradation

Biodegradation in the soil is relevant to agricultural bioplastic products, and in particular mulch films. Whilst PE films are widely used to cover crops, the material post-use is usually contaminated, and cannot be re-used, and at best only recycled into low quality polymers after extensive washing out of soil and chemical residues; but nevertheless, the films have to be collected after use and disposed of.

When extracted, they leave fragments that accumulate in soil. Bioplastics, tested to the relevant standard[8], can be designed to protect crops during the crucial growth period, but biodegrade in the soil after use, within a target period, without leaving microplastics. A new EU-UK standard has recently been published[9]. Soil biodegradation is also relevant to other horticultural products such as treeguards, cylindrical shrouds designed to protect young saplings, and gradually biodegrade in contact with soil as the tree grows. Young forests in the UK are currently littered with environmentally persistent polyolefin treeguards estimated to be in the region of 3000 tonnes annually.

Polyolefinic fossil fuel-based treeguards can persist for many years in the environment post-use. April 2021, National Forest, UK

Biodegradation in freshwater and marine environments

Achieving biodegradation of biopolymer materials in freshwater and marine environments is challenging. A standard exists for freshwater, whilst a US ASTM standard is typically used for seawater[10]. The bioplastics industry does not seek to use biodegradation in the marine environments for commercial purposes. Consumer products and packaging are not designed to end up abandoned at sea and therefore any such assertion is not justified and risks causing increased littering. However, there is a case for using marine degradable materials for things like fishing line and gear, where it is recognised that some loss of materials into the ocean is inevitable.

Oxo-degradation or oxo-biodegradation or “biotransformation”

So-called oxo-(bio)degradable materials have muddied the waters with their claims to biodegradability. All of these materials contain transition metal or starch additives designed to destabilise the polymers and accelerate their breakdown. From a chemical viewpoint, the pro-oxidation catalysts accelerate the usual oxidation processes of the polyolefin and cause disintegration into microplastics at a faster rate. They require an extended period of exposure to UV sunlight and/or heat in the unmanaged and variable open environment, during which the PE or PP polymer breaks down via a non-biological process. Eventually, as the polymer breaks into smaller fragments, some biodegradation might begin to take place. These polymers lack intrinsic biodegradability, will not work in composting processes, could well give rise to microplastics in the environment, and raise the real issue that they may destabilise the recycling stream for conventional polymers. The European Plastic Recyclers' Association has declared these products are not recyclable. The EU has banned such products, and similar bans are in place worldwide in other locations. The risk of using these materials is that they accentuate the problem of littering by using marketing claims that the plastics will disappear if littered.

Biobased materials

A further potential source of confusion for the consumer is the use of the term biobased. Essentially the biobased content of a material defines to what extent a polymer contains "new" organic carbon – renewable carbon that is actively circulating in the carbon cycle and can be derived from plants for use in polymers. In contrast, "old" carbon is fossil carbon that has been locked up in oil and gas deposits for millions of years. High biobased carbon content is an indication that a material does not deplete finite fossil fuels and thus offers a high level of sustainability and is a positive environmental indicator. It can be easily measured using radiocarbon dating methods[11]. Biodegradable and compostable polymers often have relatively high biobased contents, compared with fossil-fuel derived polymers. Note, however, that some biodegradable polymers are still made using fossil fuel carbon, in part or whole.

Similarly, it is possible that some conventional polymers, e.g., polyethylene (PE), can be derived from plants such as sugar cane. They are thus biobased, but they are not biodegradable, and cannot be processed via composting or AD, nor are they biodegradable in the soil. Thus, it is important to understand the distinction between biobased and biodegradable materials.

Conveying the message to the consumer

It is crucial to convey a clear and accurate message both B2B and to the consumer about how a particular bioplastic object should be treated. Labelling as simply "biodegradable" is unhelpful and may be misunderstood. Although a number of labelling symbols pointing at compostability are in use under the certification schemes DIN CERTCO/Austrian TuV/BPI[3], a simpler and more transparent scheme is needed. An OPRL-REAL project is underway to develop such a labelling scheme for use in the UK. This will play an important role in ensuring that bioplastic products are segregated from the conventional polymer recycling stream, and similarly in ensuring that conventional plastics do not find their way into composting or AD facilities.

Summary

Biodegradability as a property of a material should always be qualified with reference to the particular environment(s), end uses and relevant timescales.

Standards and/or protocols are largely in place for aerobic composting and anaerobic digestion, as well as soil, freshwater and marine biodegradation. These define appropriate testing environments, timescales and criteria for the useful deployment of biodegradable materials.

There is a need to simplify the messaging on biodegradability and compostability via a clearer labelling system – an initiative that is already underway in the UK.

Bioplastics are, for now, niche products, best suited to a range of specific applications where their environmental credentials offer real benefits over fossil-fuel alternatives.

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