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Plastics - Guide for vocabulary in the field of degradable and biodegradable polymers and plastic items

Kunststoffe - Leitfaden für Begriffe im Bereich abbaubarer und bioabbaubarer Polymere und Kunststoffteile

Plastiques - Guide pour le vocabulaire dans le domaine des polymères et des produits plastiques dégradables et biodégradables

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ICS:

83.080.01	Polimerni materiali na splošno	Plastics in general
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English Version

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This Technical Report was approved by CEN on 16 January 2006. It has been drawn up by the Technical Committee CEN/TC 249.

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Foreword

This document (CEN/TR 15351:2006) has been prepared by Technical Committee CEN/TC 249 “Plastics”, the secretariat of which is held by IBN/BIN.

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Introduction

Today, there are several sectors of human activity that can take advantage of degradable and biodegradable polymers, polymeric materials and items, namely the sectors of biomedical, pharmaceutical, packaging, agricultural, and environmental applications. Although they appear very much different at first sight, these applications have some common characteristics:

- the necessity to deal with the polymeric wastes when a macromolecular material or compound is to be used for a limited period of time,
- the fact that living systems have some similarities in the sense that they function in aqueous media, they involve cells, membranes, proteins, enzymes, ions, etc...,
- the fact that living systems can be dramatically perturbed by toxic chemicals, especially low molar mass ones,

Another characteristic of degradable polymeric compounds is that each sector of applications has developed its own science and thus its own terminology. In particular, surgeons, pharmacists and environmentalists do not assign the same meaning to a given word. For instance, “biomaterial” means “therapeutic material” for people working in the biomedical sector whereas it means material of renewable origin for specialists working in the sector of exploitation of renewable resources. The field of norms is another source of examples. Norms related to degradation, and/or biodegradation in these different sectors, have introduced definitions independently. The resulting mismatching and inappropriate use often lead to misunderstanding and confusion.

Because human health and environmental sustainability are more and more interdependent and, because science, applications, and norms are developed in each of these sectors, it is urgent to harmonise the terminology or to define a specific terminology when a general one is not available, so that they can be proposed to international normative organisations.

Such a task should be based on scientific and mechanistic considerations. The present technical report is an attempt to set up a common and simple terminology applicable in the various domains where degradation, biodegradation, bioassimilation, and biorecycling are major academic and industrial goals.

It is worth noting that elimination from the human (or animal) body of high molecular weight compounds is not possible unless macromolecules are degraded to low molar mass molecules. Indeed, skin, mucosa and kidney are very efficient barriers that keep high molar mass molecules entrapped in the parenteral compartments. As for the environmental life, eliminating a waste from the planet is not possible, so far. Therefore, any product or chemical that is not recycled or biorecycled is going to be stored in one way or another, i.e. as such or as biostable residue of degradation.

1 Scope

This guide provides the vocabulary to be used in the field of polymers and plastic materials and items.

The proposed terms and definitions are directly issued from a scientific and technical analysis of the various stages and mechanisms involved in the alteration of plastics up to mineralization, bioassimilation and biorecycling of macromolecular compounds and polymeric products; i.e polymeric items.

NOTE The proposed vocabulary is intended also to be in agreement with a terminology usable in various domains dealing with time limited plastic applications, namely biomedical, pharmaceutical, environmental, i.e., in surgery, medicine, agriculture, or plastics waste management.

2 Analysis of the alteration stages and mechanisms

2.1 Alteration stages

If one looks carefully at what can happen when a polymeric item is in contact with a living system, regardless of the living system (animal body, plant, micro-organisms or the environment itself), one finds different levels of alterations. These various levels are shown in Figure 1.

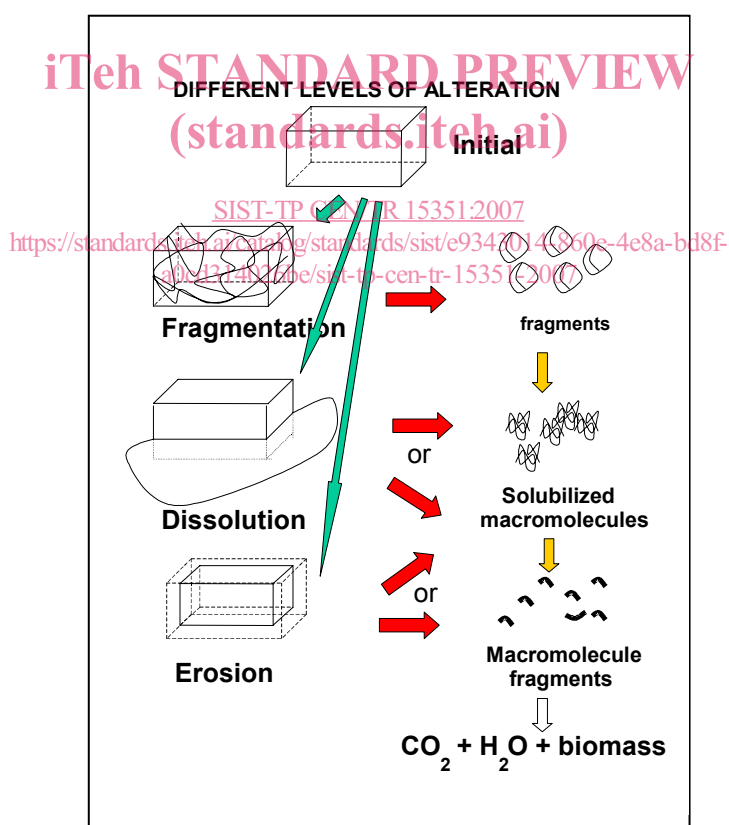


Figure 1 — The levels of alteration for a polymeric device

From this schematic presentation it appears that the formation of tiny fragments or dissolution does not necessarily correspond to macromolecule breakdown. Actually it reflects the disappearance of the initial device only. Whether the macromolecules that formed the original polymer-based item remain intact or are chemically cleaved with decrease of molar mass needs to be distinguished by specific words. This is

important in the case of an animal body because of the retention of high molar mass molecules mentioned above. In the environment, solid fragments of a polymeric device (regardless of whether the particles are visible or not) may also be recalcitrant. Similarly, macromolecules that are dispersed or dissolved in outdoor water may be absorbed by minerals and stored there, or may reach the underground water, thus resulting in dispersion as long lasting waste in Nature.

Macromolecule breakdown to “biostable” (i.e. could not be biodegraded further to minerals and biomass) small molecules is a third stage of degradation where low molar mass molecules may be generated that can be much more toxic than the original high molar mass ones. This remark raises the problem of the interactions of the degradation products with living systems. This problem is solved in the biomedical field by the use of the term “biocompatibility”. In the case of the environmental applications, there is not an equivalent word. One could extend the use of the term “biocompatibility” to express that degradable polymeric items and their degradation products have no detrimental effect on relevant living systems. Whether the generated low molar mass degradation by-products can be bioprocessed further, i.e. up to bioassimilation, or their breakdown stops at intermediate stages where the generated degradation by-products are biostable needs also to be distinguished by specific words.

The last stage of degradation is complex in the sense that it includes the formations of biomass, of CO₂ + H₂O and of some other compounds occasionally, e.g. CH₄ in the case of anaerobic biodegradation. Again, the formation of (CO₂ + H₂O) and of other inorganic residues that reflect the involvement of biochemistry in the macromolecule degradation should be distinguished from the biomass formation that shows that degradation by-products have been bioassimilated by the degrading cells. It is important to note that photooxidation of some polymers can yield CO₂ in the absence of microorganisms.

2.2 Degradation mechanisms

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Another fundamental discussion concerns the routes that can lead from a polymeric item to the ultimate stage, namely mineralisation + biomass formation.

Actually, there are two main routes that are shown in Figure 2.

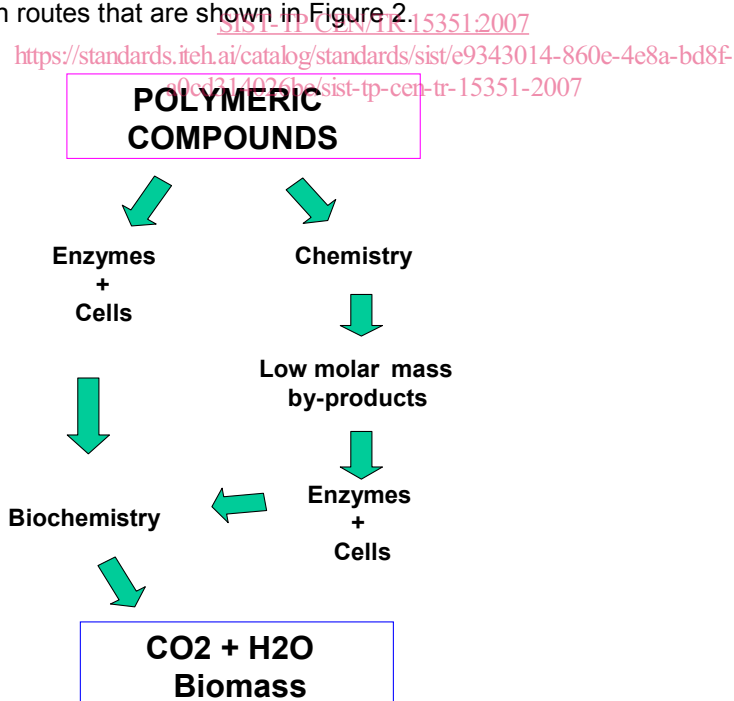


Figure 2 —The two general routes leading to bioassimilation

a) Cell-mediated polymer degradation

The left-hand side route corresponds to the attack of cells on a polymeric item or macromolecule followed by biochemical processing of the degradation products as a result of enzymatic reactions. This route requires the presence of appropriate enzymes and thus of specific cells under viable conditions (atmosphere, water, nutrients). In nature, enzymes cannot be found without the presence of living cells. In other words, no life-allowing conditions, no degradation by living systems. This raises the problem of degradation tests carried out under lab conditions with commercially available isolated enzymes. Are these isolated enzymes to be considered as causing degradation by a living system (despite the absence of the microorganisms that the enzymes are issued from) or by simple chemical degradation in the presence of a non-viable catalytic system? This question is fundamental. It has to be solved by appropriate terminology in order to avoid confusion in literature.

b) Chemistry-mediated polymer degradation

The right hand side route differs from that of the left-hand side in the sense that the breakdown of polymer-based items and macromolecules depends on chemical processes. Therefore, only the generated small molecules have to be eliminated through biochemical pathways. Here the conditions required to trigger chemical degradation are necessary (light, water, oxygen, heat...). No triggering phenomenon, no degradation. On the other hand, living cells have to be present to ensure the biochemical processing of the low molar mass molecules formed from the macromolecules of the original polymeric item. Therefore, words are necessary to distinguish these routes.

c) Combination

If one combines the several levels of degradation with these two different routes, it is again obvious that a number of specific words are required to distinguish the various possibilities.

It is worth noting that, any material is unstable when in contact with living systems for a long period of time and therefore, the terminology has to be limited to the desired degradation of polymeric items in contrast to the undesired degradation that any material eventually undergoes under the influence of use and ageing.

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3 Basic situations to be distinguished

3.1 Individualised situations

Let us first consider each possibility separately, though they can overlap to some extent:

- alteration of a polymeric item with or without disappearance in the absence of macromolecule cleavage
 - due to breakdown to small solid fragments
 - due to dissolution of macromolecules
- alteration of a polymer-based item with macromolecule cleavage
 - due to non-enzymatic chemical phenomena
 - due to abiotic enzymatic phenomena
 - due to cell-mediated degradation
 - with formation of biostable residues, regardless of the mechanism of degradation

3.2 Correlation to terms

There is the need of distinguishing these various stages and phenomena that are usually referred to inconsistently as degradation or biodegradation. A means has to be found and accepted to differentiate the physical breakdown of a polymeric item without macromolecule cleavage from the physical breakdown of this polymeric item due to chemical macromolecule cleavage. It is proposed to use the already introduced axiom saying that for macromolecular materials or systems that deteriorate acceptably in one way or another, **degradation** means alteration of macromolecules via chemical cleavage of the main chain. To technologists, this normally means “deterioration of technical performance, but to scientists it generally means “decrease of molar mass by chemical cleavage of the main chain”, which may be but not necessarily related to technical performance. The latter definition will be used in the present work.

From there, **biodegradation** is defined as the alteration of macromolecules with chain cleavage caused by cells regardless of their type (human or animal, vegetal, microbial or fungal). This biodegradation can result from cell enzymatic activity as well as from chemical reactions that can occur locally below a cell adhering to a polymeric surface because of the presence of some released non-enzymatic compounds (acids for instance). Under these conditions, degradation in the presence of isolated enzymes under laboratory conditions cannot be considered as biodegradation and the distinction has to be made clearly. The biodegradation of a polymeric item has to be related to a measurable phenomenon. The production of CO₂ and CH₄ for anaerobic process, or the consumption of O₂ are usually considered but they do not take into account the formation of biomass.

NOTE It is worth noting that, under the above conditions, the terms degradation and biodegradation give information on the mechanism of chain cleavage but do not reflect the fate of the degradation by-products.

“Fragmentation” can be selected to reflect a degradation observed at the physical level (visually or through physical measurements) which yields fragments of the original material regardless of the mechanism. If fragmentation is caused by cells, then, “biofragmentation” could be considered as pertinent. “Disintegration” could then be used to reflect fragmentation to particles smaller than a given size, “biodisintegration” reflecting the same effect caused by a cell-mediated process. Although fragmentation and disintegration can look interchangeable, it is important for practical reasons such as composting to distinguish the case where a polymeric item falls apart into pieces from the case where these pieces are below a certain measured and desired size.

The physical alteration due to the dissolution of intact macromolecules should be correlated specifically to the term “dissolution”, dissolution with macromolecule cleavage being then referred to as “degradation”.

4 The actual situations

4.1 Heterogeneous degradation

In reality, the alteration of a polymeric item by a living system is seldom as simple as described so far. We have to further consider intermediate situations and look for a finer terminology.

Let us consider first the case where degradation is not homogeneous, i.e. it is not the same throughout the whole volume or molecule. The expression “heterogeneous degradation” can be used in contrast to “homogeneous degradation”. If the alteration of a solid item is faster at the surface than inside, erosion seems to be the best word to be used. Then “bioerosion” reflects cell-mediated attack through the surface of a solid device specifically. If the degradation proceeds faster inside than outside, one could agree on the use of “bulk degradation”. It is worth noting that “bulk biodegradation” is unlikely in the case of polymers because cells and enzyme molecules are usually too large to penetrate hydrophobic polymeric matrices. An exception could be found if enzymes can penetrate in a swollen matrix like in hydrogels or if cells are entrapped and active within a polymeric matrix.

4.2 Formulated plastics

Let us now consider the case of a solid polymer-based item composed of a polymer known to undergo biodegradation as defined above. Such an item may have been formulated with additives such as organic plasticisers and mineral fillers or other compounds that are not biodegradable. On the other hand the biodegradable part of the polymeric item may not be totally available for biodegradation or some biodegradation by-products could be biostable, i.e. could not be biodegraded further to minerals and biomass. Therefore the biodegradation of such a polymer-based item may lead to various situations, depending on the bioavailability of the macromolecules to be biodegraded (Fig. 3). "Bioavailability" reflects the fact that a substance is accessible to bioprocessing by cells.

4.3 Qualifiers

According to Fig. 3, we need terminology to distinguish the maximum extent of biodegradation from the theoretical extent of biodegradation, the actual extent of biodegradation at time t , the extent of bioassimilation, and the part of the initial compounds that is transformed to biomass. To simplify, it is proposed to use the following terms: "degree of biodegradation" (W_{ba} / W_{tot}); "maximum degree of biodegradation" at infinite time ($(W_{bmin} + W_{bass}) / W_{tot}$); and "degree of bioassimilation" (W_{bass} / W_{tot}). Intermediate values observed during the degradation process will then be "degree of biodegradation" and "degree of bioassimilation at time t ".

It is of value to note that, basically, abiotic degradation can occur during biodegradation and thus it is very important to recommend the use of the term "bioassimilation" in parallel to "degradation" and "biodegradation" if one wants to distinguish chemical chain breaking from biological chain breaking and biomass formation. Of course, if the degradation by-products issued from abiotic degradation are mineralised or bioassimilated, the balance will take them as biodegradable. Otherwise, the residues will appear as non biodegradable and non-bioassimilable.

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