OXO-BIODEGRADABLE PLASTICS ASSOCIATION

20 Hanover Square, London W1S 1JY, England
www.biodeg.org

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By Professor Gerald Scott DSc, FRSC, C.Chem, FIMMM, Professor Emeritus in Chemistry and Polymer Science of Aston University UK; Chairman of the British Standards Institute Committee on Biodegradability of Plastics, Chairman of the Scientific Advisory Board of the Oxo-biodegradable Plastics Association.

I have been asked by Symphony Environmental Technologies (UK) to respond to a request from Bioplastics Magazine for an article about their d_2w Controlled-life plastics, which degrade by a process of oxo-biodegradation.[6] My views are based on the research carried out in my own and in many other laboratories throughout the world since my original patent was filed in 1971, and on my review of independent test reports carried out on d_2w products.

Let us be clear at the outset that oxo-biodegradable plastic is not normally marketed for composting, and it is not designed for anaerobic digestion nor for degradation deep in landfill. Let us also be clear that oxo-biodegradable plastic is not designed to merely fragment – it is designed to be completely bioassimilated by naturally-occurring micro-organisms in a timescale longer than that required for composting (180 days) but shorter than for nature's wastes such as leaves and twigs (10 years or more), and much shorter than for normal plastics (many decades). All plastics will eventually become embrittled, and will fragment and be bioassimilated, but the difference made by oxo-biodegradable technology is that the process is accelerated.

Oxo-biodegradable plastic is intended to address the environmental problem caused by plastic waste which gets accidentally or deliberately into the open environment. This is a well known problem in all countries, and cannot be ignored by calling it a behavioural issue. Oxo-biodegradable plastic is designed to harmlessly degrade then biodegrade in the presence of oxygen and to return the carbon in the plastic to

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1 Emeritus Professor of Chemistry and Polymer Science, Aston University
2 Professor of Chemistry at Ecole Nationale Supérieure de Chimie de Clermont-Ferrand and Université Blaise Pascal Clermont-Ferrand).
3 Associate Professor of Physical Chemistry, University of Gothenburg
4 Professor of Chemistry, Federal University of Rio Grande do Sul, Brasil
5 Ph. D. Australian National University, Molecular Microbial Ecology; M. Sc. Medical Microbiology, and B. Sc., Botany, Zoology and Chemistry, Mysore University, India.

6 Oxo-biodegradation is defined by CEN/TR15351-06 as "degradation identified as resulting from oxidative and cell-mediated phenomena, either simultaneously or successively."

the natural biological cycle. Accordingly, tests in anaerobic conditions or in composting conditions are not appropriate

Industrial composting is not the same as biodegradation in the environment, as it is a process operated according to a much shorter timescale than the processes of nature. EN13432 (and similar composting standards such as ISO 17088, ASTM D6400, ASTM D6868, and Australian 4736-2006) are not relevant to oxo-biodegradable plastic. Indeed EN13432 itself says that is not appropriate for plastic waste which may end up in the environment through uncontrolled means.

Oxo-biodegradable plastic products are normally tested according to ASTM D6954-04 “Standard Guide for Exposing and Testing Plastics that Degrade in the Environment by a Combination of Oxidation and Biodegradation.” There are two types of Standards – Standard Guides and Standard Specifications ASTM 6954 is an acknowledged and respected Standard Guide for performing laboratory tests on oxo-biodegradable plastic. It has been developed and published by ASTM International – the American standards organisation – and the second Tier is directed specifically to proving biodegradation.

Tests performed according to ASTM D6954-04 tell industry and consumers what they need to know – namely whether the plastic is (a) degradable (b) biodegradable and (c) non phyto-toxic. It is not necessary to refer to a Standard Specification unless it is desired to use the material for a particular purpose such as composting, and ASTM D6954-04 provides that if composting is the designated disposal route, ASTM D6400 should be used.

ASTM D6954-04 not only provides detailed test methods but it also provides pass/fail criteria. The oxo-biodegradable plastics most commonly used consist of single polymers to which section 6.6.1 applies. This section requires that 60 % of the organic carbon must be converted to carbon dioxide. Therefore if the material does not achieve 60% mineralisation the test cannot be completed and the material cannot be certified.

Having achieved 60% mineralisation, the Note to 6.6.1 provides that testing may be continued to better determine the length of time the materials will take to biodegrade. It is not however necessary to continue the test until 100% has been achieved, because it is possible, by applying the Arrhenius relationship[7] to the test results, to predict the time at which that is likely to occur.

There is no requirement in ASTM D6954-04 for the plastic to be converted to $C0_2$ in 180 days because, while timescale is critical for a commercial composting process, it is not critical for biodegradation in the environment. Timescale in the natural environment depends on the amount of heat, light, and stress to which the material is subjected, and as indicated above, nature’s wastes such as leaves twigs and straw may take ten years or more to biodegrade.

The requirement in EN13432, ASTM D6400 and similar standards for 90% conversion to CO_2 gas within 180 days is not useful even for composting, because it contributes to climate change instead of contributing to the fertility of the soil. “Compostable” plastic, 90% of which has been converted to CO_2 gas, is virtually useless in compost, and nature's lignocellulosic wastes do not behave in this way.

The applications for which oxo-biodegradable plastics are normally used can vary from very short-life products such as bread-wrappers intended to last a few months, to durable shopping bags intended to last five years or more. The conditions under which they are likely to be discarded can also vary from cold and wet conditions to hot and dry desert conditions. It is for the companies producing or using these products to evaluate the test results to judge the suitability of the tested material for those applications and conditions, and to market them accordingly.

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[7] See eg. Jakubowicz, :Polym. Deg. Stab. 80,39-43 (2003)

The pro-oxidant additives which cause accelerated degradation are usually compounds of iron, nickel, cobalt, or manganese together with carefully-formulated stabilisers, and are added to conventional plastics at the extrusion stage. These reduce the molecular weight of the material – causing it to be ultimately consumed by bacteria and fungi. Symphony's d_2w additives have been tested and proved not to be phyto-toxic, and they do not contain "heavy metals."

Oxo-biodegradable technology is commonly used for Polyethylene and Polypropylene products, but it can also be used for Polystyrene. Experiments are continuing with PET but I am not as yet satisfied that the technology will work satisfactorily with PET. Experiments are also continuing with PVC.

Tests on oxo-biodegradable plastic products are usually conducted by independent laboratories such as Smithers-RAPRA (US/UK), Pyxis (UK), Applus (Spain), etc. according to the test methods prescribed by ASTM D6954-04. Conditions in the laboratory are designed to simulate so far as possible conditions in the real world, but have to be accelerated in order that tests may be done in a reasonable time. Pre-treatment does not invalidate the results.

In the real world the temperature of the soil varies between 0 and 50°C depending on the location. The rate of molar-mass reduction and biodegradation can be extrapolated for any soil temperature by means of the Arrhenius relationship.[8]

I have read many independent laboratory test reports on oxo-biodegradable materials supplied by Symphony and by other manufacturers, which are entirely consistent with the published scientific literature[9] and with my own research. These manufacturers are not surprisingly unwilling to disclose their data to their competitors, but having seen the reports I am satisfied that if properly manufactured, oxo-biodegradable products will totally biodegrade in the presence of oxygen.

I am aware of suggestions that fragments of plastic (whether oxo-biodegradable, compostable, or normal plastic) attract toxins in a marine environment and are ingested by marine creatures. I am not however persuaded that fragments of plastic are any more likely to attract toxins than fragments of dead seaweed or any of the other trillions of fragments which are always present in the sea.

I regard it as a positive factor that oxo-biodegradable plastics are made from naphtha - a by-product of oil, which used to be wasted. For so long as the world needs petroleum fuels and lubricants for engines it makes good environmental sense to use this by-product.

I agree with the June 2009 report from Germany's Institute for Energy and Environmental Research, which concluded that oil-based plastics, especially if recycled, have a better Life-cycle Analysis than compostable plastics. They added that "The current bags made from bioplastics have less favourable environmental impact profiles than the other materials examined" and that this is due to the process of raw-material production." (see e.g. http://www.biodeg.org/files/uploaded/biodeg/Hydro-biodegradable_Plastic_Production_Process.pdf).

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[8] See D. Gilead and G. Scott "Developments in Polymer Stabilisation"-5. App. sci. Pub., 1982, Chapter 4 and references therein for details of environmental effects on oxo-biodegradation

[9] There is insufficient space here for all the relevant publications, but see the following reviews for some of the recent papers. "Degradation and Stabilisation of Carbon-chain polymers", G. Scott in "Degradable Polymers: Principles and Applications," Kluwer,2002, Chapter 3. "Degradable Polymers in waste and litter control", G, Scott and D.M. Wiles, ibid. Chapter 13. "Oxo-biodegradable Polyolefins", D.M. Wiles, "Biodegradable Polymers for Industrial Applications" ed. R. Smith, CRC Press, 2005, Chapter 3. "Standards for Environmentally Biodegradable Plastics", G. Scott, ibid, Chapter 12. "Biodegradable Polymers in Agriculture," G, Scott, ibid, Chapter 17. Chiellini et al "Oxo-biodegradable full carbon backbone polymers and biodegradation behaviour of thermally oxidized polyethylene in an aqueous medium." Polymer Degradation and Stability 92 (2007) 1378e1383. International Biodeterioration & Biodegradation 63 (2009) 354–357

Compostable plastics are designed to be deliberately destroyed in the composting process, but oxo-biodegradable plastics can be re-used many times and can be recycled if collected during their useful lifespan, which in the case of shopper-bags is about 18 months. Plastics of any kind should not be used for home-composting as they are often contaminated with meat and fish residues and temperatures may not rise high enough to kill the pathogens.

It is not desirable to send otherwise recoverable plastic to landfill, as plastic is a valuable resource. Nor is it desirable for anything to degrade in landfill unless the landfill is designed to collect the resulting gases, which most are not. However if oxo-biodegradables do end up in landfill, they are designed to disintegrate and partially biodegrade at or near the surface. Any particles deep in anaerobic landfill are minimal, and will remain inert indefinitely. They can never emit methane – unlike compostable plastics, paper, etc.

So far as recycling is concerned, oxo-biodegradable plastic can be recycled in the same way as ordinary plastic (see http://www.biodeg.org/position-papers/recycling/?domain=biodeg.org). By contrast, “compostable” plastic cannot be recycled with ordinary plastic, and will ruin the recycling process if it gets into the waste stream.

APPENDIX

Key scientific papers on the biodegradation of polyolefins

Reviews

1. Environmental Biodegradation of Hydrocarbon Polymers, G.Scott, *Biodegradable Plastics and Polymers*, Eds.. Y.Doi and K.Fukuda, Elsevier Science BV, 1994, pp 79-91.
2. Abiotic control of Polymer Biodegradation, G.Scott, *Trends in Polymer Science*, **5**, 361-368 (1997).
3 Antioxidant Control of Polymer Biodegradation, G.Scott, in *Degradability, Renewability and Recycling; 5th International Scientific Workshop on Biodegradable Plastics and Polymers*, Macromolecular Symposia, Eds. A -C.Albertsson, E.Chiellini, J.Feijen, G.Scott and M.Vert, Wiley-VCH, Weinheim, 1999, 113-125.
4. Degradable Polymers in Waste and Litter Control, G.Scott and D.Gilead in *Degradable Polymers: Principles and Applications*, Chapman & Hall, 1995, Chapter 13.
5. Plastics and the Environment, J.Guillet, in *Degradable Polymers: Principles and Application*, Chapman & Hall, 1995, Chapter 12.
6. Biodegradable Polymers, G.Scott, *Polymers and the Environment*, Royal Society of Chemistry, 1999, Chapter 5.
7. The role of Environmentally Degradable Polymers in Waste Management, G.Scott, *Wastes Management*, May 1999, 38-39.
8. ‘Green Polymers’, G.Scott, *Polym. Deg. Stab.*, **68**, 1-7 (2000)
   Environmentally degradable polyolefins: When, Why and How, G.Scott in *Expert group meeting on Environmentally degradable plastics, Present Status and perspectives*, ICS-UNIDO, Trieste, 2001, p. 37-48.
9. Why degradable polymers, G.Scott in *Degradable Polymers: Procíples and Applications*, 2nd Edition, Ed. G. Scott, Kluwer Academic Publishers, 2002, Chapter 1, p. 1-15.
10. Degradation and stabilisation of carbon-chain polymers, G.Scott in *Degradable Polymers: Procíples and Applications*, 2nd Edition, Ed. G. Scott, Kluwer,

Academic Publishers, 2002, Chapter 3, p. 27-50.
11. Degradable hydrocarbon polymers in waste and litter control, G. Scott and D.M.Wiles in *Degradable Polymers: Procuples and Applications*, 2nd Edition, Ed. G.Scott, Kluwer Academic Publishers, Chapter 13, p.449-479.
12. Science and Standards, G.Scott in *Biodegradable Polymers and Plastics*, Eds. E.Chiellini and R.Solero, Kluwer Acadademic Publishers, Chapter 1, pp.3-32.
13 Oxo-biodegradable polyolefins, D.M.Wiles in *Biodegradable Polymers for Industrial Applications*, , ed. R. Smith, Woodhead Publishing Company, Chapter 3, 2005.
14 Standards for Environmentally Degradable Plastics, G. Scott in *Biodegradable Polymers for Industrial Applications*, , ed. R. Smith, Woodhead Publishing Company, Chapter 12, 2005.
15 Oxo-biodegradable Plastics in Packaging, D.M. Wiles in *Biodegradable Polymers for Industrial Applications*, , ed. R. Smith, Woodhead Publishing Company, Chapter 16, 2005.
16 Biodegradable Plastics in agriculture, G. Scott in *Biodegradable Polymers for Industrial Applications*, , ed. R. Smith, Woodhead Publishing Company, Chapter 17, 2005.

Experimental Studies

1. Oxidative Degradation and Molecular Weight Change of LDPE Buried under Bioactive Soil for 32-37 Years, Y. Ohtake et al., *Journal of Applied Polymer Science* **70**, 1643-1659 (1998).
2. Studies on biodegradation of LDPE - observation of LDPE films scattered in agricultural fields or in garden soil, Y. Ohtake et al. *Polym. Deg. Stab.* **60**, 79-84 (1998).
3. Molecular Weight Changes and Polymeric Matrix Changes Correlated with the Formation of Degradation Products in Biodegraded Polyethylene, A-C Albertsson et al., *J. Environ. Polym. Deg.*, **6,** 87-195 (1998).
4. Biodegradable Polymers and Environmental Interaction, S. Karlsson and A-C Albertsson, *Polymer Engineering and Science* **38**, 1251-1253 (1998).
5. Biodegradability of Scott-Gilead Photodegradable Polyethylene and Polyethylene wax by microorganisms, F.Kawai, M.Shibata, S.Yokoyama, S.Maeda, K.Tada and S.Hayashi, *Degradability, Renewability and Recycling, 5th International ScientificWorkshop on biodegradable Plastics and Polymers,* Macromolecular Symposia, eds. A-C.Albertsson, E.Chiellini, J.Feijen.
6 . Photooxidation and Biodegradation of Commercial Photodegradable Polyethylenes, R.Arnaud, P.Dabin, J.Lemaire, S.Al-Malaika, S.Chohan, M.Coker, G.Scott, A.Fauve and A. Maarooufi, *Polym. De. Stab.*, **46**, 211-224 (1994).
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9 Evaluation of biodegradable polyethylene (PE), I. Jakubowicz, *Polym. Deg. Stab.*, **80**, 39-43 (2003).
10 Biodegradation of thermally oxidised, fragmented low-density polyethylenes, E. Chiellini, A. Corti and G. Swift, *Polym. Deg. Stab.*, **81**,341-351.
11 Environmental biodegradation of polyethylene, S.Bonhomme, A. Cuer, A-M. Delort, J. Lemaire, M.Sancelme and G.Scott, *Polym. Deg. Stab.*, **81**, 441-452 (2003)