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RECYCLING BIOPOL—COMPOSTING AND MATERIAL RECYCLING

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ABSTRACT

The recycling of biodegradable thermoplastics such as ZENECA's BIOPOL range of poly-3-hydroxybutyrate and poly-3-hydroxyvalerate copolymers needs to be considered in terms of both material recycling and organic recycling by composting. BIOPOL can be recycled as regrind. The addition of BIOPOL to a model waste stream demonstrates that at the anticipated addition levels, BIOPOL should not have a deleterious effect on the processing or properties of the thermoplastic waste stream. Therefore, BIOPOL should not compromise the recycling initiatives underway. Recycling BIOPOL by composting not only offers an additional waste management option where material recycling is not a viable option for technical, economic, or environmental reasons, but also generates a useful product, valuable as a soil conditioner.

INTRODUCTION

There has been an increase in both the quantity of waste generated and public concern over its effect on the environment. Plastic packaging waste is a particularly visible problem and represents 20–30% of the waste stream by volume (although only ~7% by weight). It is generally recognized that there is no single, simple solution to waste management. A range of waste management options exist which either reduce the amount of material entering the waste stream or deal with its disposal. A hierarchy of waste management options appears to be arising which consists of reduce, reuse, recycle (including composting), incineration, and landfill, in decreasing order of desirability. These options are applicable to plastic waste.

Up to 60% of municipal solid waste is organic and potentially compostable. Composting has significant potential to not only offer an alternative waste disposal option for a significant proportion of waste, but also to generate a useful product, valuable as a soil conditioner. Composting can be considered to be an organic recycling process. The use of biodegradable polymers in packaging organic/biodegradable contents such as food potentially enables all of the resultant waste to be composted without requiring separation of contents and packaging. Composting is particularly pertinent where material recycling is not a viable option for technical, economic, or environmental reasons. A significant increase in the levels of composting is expected to result in a significant diversion of material from landfilling.

ZENECA's BIOPOL range of poly-3-hydroxybutyrate and poly-3-hydroxyvalerate bacterial copolyesters are compatible with the range of waste management options. It has been demonstrated that BIOPOL can be recycled in the traditional sense as regrind or in a model mixed plastic waste stream without adversely affecting the processing of properties of the latter and therefore should not compromise the recycling initiatives underway. In addition, BIOPOL can be organically recycled by composting. Indeed, both forms of recycling can be practiced. BIOPOL can be initially materially recycled (say as regrind) and then finally organically recycled by composting. Therefore, the recycling of BIOPOL should be considered in terms of both material recycling (as for conventional thermoplastics) and organic recycling by composting (which requires biodegradation).

MATERIAL RECYCLING

Material recycling involves the reprocessing of the polymer, either alone or with other polymers.

During melt processing of a polymer by, say, injection molding, waste is produced in the form of sprues and runners and substandard parts. This waste can be readily collected and kept free of contamination, and is, therefore, of good quality provided excessive thermal degradation has not occurred during processing. The sprues, etc. are reground, mixed with virgin material, and melt processed into finished articles. This use of regrind is a common form of material recycling to reduce the material costs of production. Typically 20% regrind levels are used.

Once the articles have been sold, used, and disposed of, they can then also potentially be recycled. To recycle the polymer alone it must be collected, identified, and separated from the other waste. Excessive contamination of the polymer (e.g., with food) and the use of composite articles may prevent cost-effective recycling of this postconsumer waste.

Recycling of a mixed plastic waste stream avoids the need to identify a specific plastic and separate different plastics, but tends to produce a lower quality, variable product. Mixed plastic waste streams therefore tend to be used for relatively undemanding applications.

BIOPOL Regrind

BIOPOL is a thermoplastic, and regrind can be added and mixed with virgin material, as for conventional thermoplastics. Regrind levels of up to 20% are generally recommended for BIOPOL.

Experimental evidence has been obtained to demonstrate that BIOPOL regrind can be used.

Unfilled BIOPOL

BIOPOL copolymer with 11% hydroxyvalerate (HV) content was subjected to a number of processing (melt extrusion/granulation) cycles. After each extrusion/granulation cycle a sample was injection-molded and mechanical properties measured. This therefore represents the use of 100% BIOPOL regrind at each stage. Up to four reprocessing cycles were used; that is, reprocessing 100% BIOPOL regrind up to four times. This is therefore a severe test of the suitability of BIOPOL regrind for general use in melt processing BIOPOL.

The data show that reprocessing 100% BIOPOL regrind four times had little deleterious effect on tensile strength, elongation at break, flexural modulus, flexural strength, and heat distortion temperature. As expected, some decrease in impact strength was observed, with four reprocessing cycles of 100% BIOPOL regrind reducing notched Izod impact strength by ~18%.

BIOPOL Bottle Grades

Bottles were extrusion blow-molded using virgin and 100% regrind in BIOPOL grades D410G and D411G. Horizontal and vertical test pieces were then cut out of the bottles and mechanical properties measured. Again, this is a severe test of the use of BIOPOL regrind since levels of up to 20% are recommended, and 100% regrind was used in these experiments.

The data for the virgin and 100% regrind bottles show that values for tensile strength, elongation at break, and modulus are similar. As expected, some decrease in energy to break of approximately 20% was observed. Scatter in the data was evident, which was expected since test pieces were cut from actual bottles.

BIOPOL in a Mixed Plastic Waste Stream

The wide range of properties required from polymers for packaging and other applications necessitates the use of a wide range of polymers. These eventually arise in the waste stream. Since the properties of a mixed plastic waste stream are variable and somewhat inferior, with consequent limited applications, the emerging recycling industry aims to recycle the major bulk commodity plastics as separate waste streams. The Society of Plastics Industry (SPI) Classification divides the recyclable thermoplastic waste stream into seven broad categories. Class 1 is polyethylene terephthalate (PET), Class 2 is high density polyethylene (HDPE), Class 3 is polyvinyl chloride (PVC), Class 4 is low density polyethylene (LDPE), Class 5 is polypropylene (PP), Class 6 is polystyrene (PS), and Class 7 contains all other thermoplastics. Currently, BIOPOL is included in Class 7.

Sales estimates for the year 2000 of conventional plastics and BIOPOL indicate that BIOPOL will represent much less than 1% of the total thermoplastics waste stream. In practice, BIOPOL would be expected to be recycled with Class 7 materials, for which by the year 2000 it would represent less than 1% of the total. At these low levels, any effect of BIOPOL on the quality and properties of such mixed waste streams is expected to be minimal.

This was tested experimentally by preparation of a model mixed polymer waste stream. 1% BIOPOL copolymer (with 10% HV content) was added to a mixed polymer blend containing 40% LDPE, 25% PP, 15% high impact PS, 10% PVC, 2.5% acrylonitrile-butadiene-styrene (ABS), 2.5% nylon, 2.5% polycarbonate (PC), and 2.5% polyacetal. The resultant blend was extruded, granulated, and injection-molded at temperatures up to 245°C with no significant difficulties. The model mixed polymer waste without BIOPOL exhibited an impact strength of 39.3 J/m, a tensile strength of 14.1 MPa, and a Young's modulus of 393 MPa compared with values of 39.8 J/m, 13.2 MPa, and 397 MPa, respectively, for the waste plus 1% BIOPOL. This confirms that the effect of BIOPOL on a mixed polymer waste stream is minimal at levels of 1%.

On rare occasions it may be possible for relatively higher levels of BIOPOL to be present in a mixed polymer waste stream. A large range of blends of BIOPOL and other thermoplastics have been investigated within ZENECA and externally which demonstrate the effect of varying BIOPOL levels on blend properties. These experiments have also demonstrated that BIOPOL can be successfully melt-processed over a range of temperatures with a wide range of polymers, including LDPE, PP, PS, PVC, ABS, nylon, polyacetal, PC, polyvinyl alcohol, polycaprolactone, and high-density polyethylene (HDPE). BIOPOL is melt processible in conventional extruders and does not require special preparation prior to melt processing.

BIOPOL bottle grade D411G white 1001 and unfilled HDPE were tumble blended to produce blends with 1, 5, and 10% by weight BIOPOL, extruded and injection-molded under the same conditions as a HDPE control. BIOPOL was readily melt processed with HDPE at levels up to 10% (the maximum used in this experiment). The addition of 1% BIOPOL to HDPE had little effect on melt flow index (MFI) and mechanical properties (tensile strength, Young's modulus, and Izod impact strength). Addition of 5% and above of BIOPOL to HDPE caused some loss of mechanical properties (particularly impact strength), but useful properties were still maintained at the 10% level.

Higher levels of BIOPOL were readily melt-blended with LDPE. Addition of 20, 30, and 40% BIOPOL to LDPE progressively increased modulus and decreased tensile strength and elongation at break.

Addition of BIOPOL to certain polymers such as PVC and polyacrylonitrile has a beneficial effect.

BIOPOL appears to be at least partially miscible with PVC, and blends have been successfully extruded and molded. BIOPOL has shown some promise as a processing aid in rigid PVC formulations. Addition of 20% BIOPOL to PVC (by weight) increased the falling weight impact energy to break for 3.9 to 24.0 J.

BIOPOL also appears to be effective as a processing aid for polyacrylonitrile, with addition of small quantities significantly reducing the power required for extrusion. Addition of 2 phr (parts per hundred of resin) of BIOPOL to a 35% nitrile group containing polyacrylonitrile increased Young's modulus, tensile strength, elongation to break, and notched Izod impact strength (from 3.63 GPa, 57 MPa, 10–20%, and 110–150 J/m to 4.18 GPa, 68 MPa, 33–36%, and 370–500 J/m, respectively).

Biodegradation studies on blends of BIOPOL with other polymers have been undertaken within ZENECA and externally. Addition of BIOPOL to a nonbiodegradable polymer such as PP does not cause biodegradation of the PP. In soil burial tests at 25°C, the weight loss after 63 days of 100% BIOPOL and 10% BIOPOL/90% PP blend films was 71.4 and 0.14%, respectively. This shows that when BIOPOL is present in small quantities ($\leq 10\%$) and encapsulated within the nonbiodegradable PP matrix, the microorganisms cannot readily access the BIOPOL and biodegradation of the BIOPOL is rendered insignificant. The PP does not biodegrade. Therefore the presence of small quantities of BIOPOL in a mixed plastic waste stream should not affect stability with respect to biodegradation.

Blends of BIOPOL with other biodegradable polymers such as polycaprolactone biodegrade as expected.

In conclusion, BIOPOL is likely to be recycled in the SPI Class 7 category and at the anticipated level of $<1\%$ is not expected to significantly adversely affect the melt processing of the mixed plastic waste stream or its properties (including stability to biodegradation). Naturally, as for other polymers, the inclusion of BIOPOL in a separate pure waste stream such as PET should be avoided.

COMPOSTING—ORGANIC RECYCLING

Composting may be defined as the aerobic biodegradation of organic material to form primarily carbon dioxide, water, and humus.

Like material recycling, organic recycling of biodegradable materials such as BIOPOL requires collection and separation (from nonbiodegradable impurities). The large (up to 60%) quantity of municipal waste that is organic and therefore potentially compostable is encouraging the continued development of composting facilities. Use of BIOPOL packaging for compostable waste simplifies the composting process by avoiding the need to separate the contents from the packaging. In addition, use of BIOPOL bags for waste further simplifies the process, since the entire bag and contents can be added to the compost stream.

The organic recycling of BIOPOL by composting has been extensively studied at the industrial scale and under a range of composting conditions.

Initial studies conducted at an industrial composting plant in Germany indicated that up to 80% of the weight of BIOPOL bottles was biodegraded or fully incorporated into compost within 15 weeks. Any remaining material consisted of small fragments with signs of active degradation on the surface.

Recently the composting of BIOPOL has been extensively studied over a wide range of conditions (which may be encountered in practice) by the Ingenieurgemeinschaft Witzenhausen (igw-Kompostverwertung)/Plan Co Tec with Kassel University in Germany. A full report will be issued. In summary, BIOPOL is compostable over a wide range of temperatures and moisture levels, with maximum biodegradation rates occurring at moisture levels of ~55% and temperatures of ~60°C. These conditions are similar to those observed in most large-scale composting plants. No significant differences were observed in the biodegradation rates between the different BIOPOL grades evaluated.

Up to 85% of the BIOPOL samples degraded within 7 weeks under these controlled composting conditions. In addition, BIOPOL-coated paper was rapidly degraded and assimilated completely into compost.

The quality of the final compost is judged by the growth of seedlings in it. Seedling growth in control compost was compared to that in mixtures of control compost and 25% BIOPOL compost. Plant growth of over 90% that observed in the control compost is considered to indicate compost of acceptable quality. Composts containing 25% BIOPOL compost produced seedling growth approximately 125% of that in the control compost. Therefore, not only is BIOPOL compostable, but the resultant compost is of high quality, supporting a relatively high level of seedling growth.

CONCLUSIONS

BIOPOL is compatible with a wide range of disposal and waste management options. BIOPOL can be recycled through two distinct routes, material recycling and organic recycling (composting).

BIOPOL regrind can be added to virgin material for material recycling, as with other plastics, with little effect on mechanical properties. Regrind levels of up to 20% are recommended.

Addition of the anticipated levels of BIOPOL to a mixed plastics waste stream should not have a deleterious effect on the properties or processing of the thermoplastic recycling waste stream.

Organic recycling by composting is applicable for up to 60% of municipal solid waste and can generate a useful product, valuable as a soil conditioner. Addition of BIOPOL to a composting stream produces compost of high quality which supports a relatively high level of seedling growth.

Organic recycling by composting offers an alternative waste management option where material recycling is not a viable option for technical, economic, or environmental reasons.