Recyclability Comparison:
HIPS containing Earthwise™ GreenArmor™ and Commercial PC/ABS containing RDP

The recycle evaluations performed on HIPS containing Earthwise™ GreenArmor.™
With the importance of electronics and electrical equipment (EEE) end-of-life (EOL), comes research to determine the viability of various EOL options. For flame retardant plastics used in EEE applications, mechanical recycle, feedstock recovery (for brominated flame retardant systems), and waste-to-energy recovery are all acceptable options. Mechanical recycle of plastics from EEE applications is growing in importance. This growth results in materials for use in the original or in downgraded applications, depending on the thoroughness of sorting, dismantling, identification, and shredding of large parts.

Mechanical recycle of plastics from EEE applications is growing in importance.

GreenArmor and all Earthwise products are committed to the principles of green chemistry where the entire life cycle of a product from design and innovation, to minimizing the use of raw materials and energy, through the manufacturing process and down to the final stages of recycling or reusing commercial by-products are addressed.

The recycle evaluations performed on HIPS containing Earthwise GreenArmor and commercial PC/ABS containing resorcinol diphenyl phosphate (RDP) include the following:

- Multi-pass 100% recycle evaluation
- Extended heat and humidity recycle evaluation

The multi-pass 100% recycle evaluation consisted of injection molding each material, saving test parts, grinding the remainder of the test specimens, and injection molding this regrind into test specimens for a total of five injection molding cycles. The commercial formulation was dried as specified by the manufacturer prior to each molding cycle. Physical and flammability properties were then measured on each material.

The ability to maintain superior flame retardancy after being recycled is of the utmost importance for optimal mechanical recycle schemes.
The HIPS containing GreenArmor maintained the UL-94 V-0 rating after the fifth injection molding cycle. The commercial PC/ABS containing RDP had a UL-94 V-1 rating after the first injection molding and after the fifth injection molding, the UL-94 rating of this material was reduced to a V-2 rating due to drips that ignited the cotton in multiple test specimens.

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Susan D. Landry, Albemarle Corporation, Sept. 4, 2009

Figure 1 contains the results from these evaluations in terms of % property retention on several of the significant properties for these formulations.
The IZOD impact strength of the commercial PC/ABS formulation containing RDP was significantly reduced during this recycle evaluation.

Figure 1 - Multi-Pass Recycle Evaluation From 1st to 5th Injection Molding of HIPS Containing Earthwise GreenArmor and Commercial PC/ABS Formulations

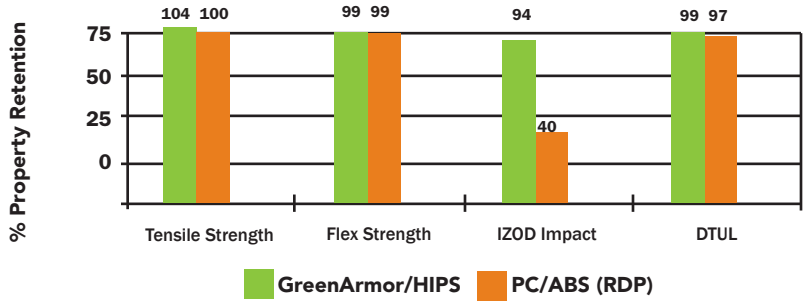
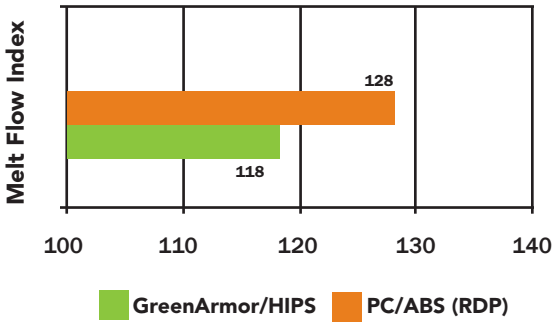


Figure 2 also contains results from this evaluation.
In terms of % melt flow index retention; however, the values are 100% since the melt flow index increased. Both graphs demonstrate the excellent recyclability of the HIPS containing GreenArmor as compared to commercial PC/ABS containing RDP.

Figure 2 - Multi-Pass Recycle Evaluation From 1st to 5th Injection Molding of HIPS Containing Earthwise GreenArmor and Commercial PC/ABS Formulations



The extended heat and humidity recycle evaluation was intended to simulate the potential exposure of EEE to heat and humidity via outdoor storage at EOL. It consisted of injection molding each of the same materials used in the multi-pass recycle evaluation, saving test specimens, and subjecting the remainder of the test specimens to accelerated heat and humidity conditions of 80°C and 95% relative humidity for 168 hours. Upon aging, the parts were ground into small pieces.

Blends of the aged materials and the respective dried neat resin from the bag (prior to injection molding) were injection molded and evaluated as follows:

- 0% aged material (100% neat resin) wt%
- 30% aged material (70% neat resin) wt%
- 100% aged material (0% neat resin) wt%.

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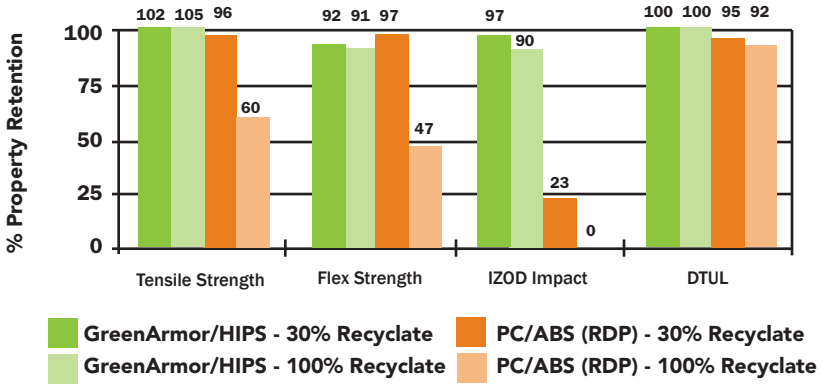
As in the previous recycle evaluation, the three materials were dried at conditions specified by the manufacturer prior to each molding cycle. Physical and flammability properties were measured on each material at each blend ratio of neat resin and humid aged material.

The HIPS containing GreenArmor maintained the UL-94 V-0 rating in both the 30% aged recyclate (70% neat resin), and the 100% aged recyclate evaluations. The commercial PC/ABS containing RDP maintained the UL-94 V-1 rating in the 30% aged recyclate evaluation. In the 100% aged recyclate evaluation, the UL-94 rating of the PC/ABS containing RDP UL-94 was reduced to a V-2 due to drips that ignited the cotton in multiple test specimens.

Figure 3 contains the results from the recycle evaluations in terms of % property retention on several of the significant properties for these formulations.
Note both the % property retention of the 30% aged material, or recyclate (70% neat resin), and the 100% aged material, or recyclate are both included in this graph.
At 30% humid aged recyclate, the IZOD impact strength of the commercial PC/ABS formulation containing RDP was significantly reduced.

The HIPS containing GreenArmor remain reasonably stable under extreme conditions.

Figure 3 - Extended Heat & Humidity Recycle (30% & 100% Humid Aged Recyclate) of HIPS Containing GreenArmor and Commercial PC/ABS (RDP) - % Property Retention



At 100% humid aged recyclate, the tensile strength and flex strength of the commercial PC/ABS formulation containing RDP decreased dramatically and IZOD impact strength was extremely bad. The HIPS containing GreenArmor remained reasonably stable under these extreme conditions.

Figure 4 also contains results from this extended heat and humidity evaluation.
In terms of % melt flow index retention; however, the values are 100% since the melt flow index increased. While the melt flow index of the HIPS containing GreenArmor remained very stable, the commercial PC/ABS formulation containing RDP showed dramatic increases in melt flow index, which is indicative of polymer degradation. Both graphs demonstrate the excellent recyclability of HIPS containing GreenArmor under extremely harsh conditions that much of waste EEE could be exposed to.

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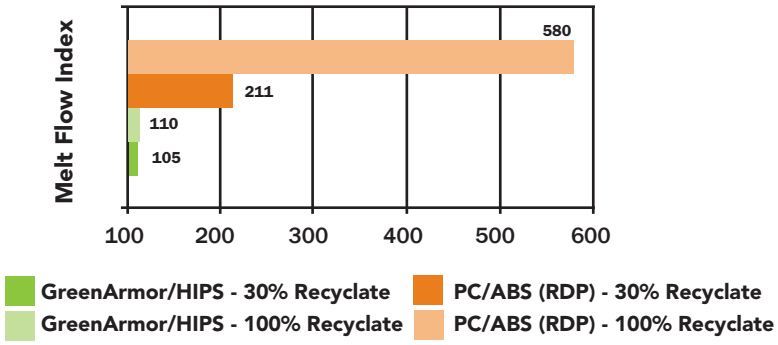
Figure 4 - Extended Heat & Humidity Recycle (30% & 100% Humid Aged Recyclate) HIPS Containing GreenArmor and Commercial PC/ABS Formulations - % Property Retention



The results clearly show that the HIPS containing GreenArmor has superior recyclability to the PC/ABS containing RDP.

The results clearly show that the HIPS containing GreenArmor has superior recyclability to the PC/ABS containing RDP. In each of the recycle evaluations, IZOD impact strength was significantly reduced in the PC/ABS containing RDP, while the HIPS containing GreenArmor had extremely good property retention, including fire retardancy. In the extended heat and humidity recycle evaluation, the increase in melt flow index and decrease in other properties in the PC/ABS containing RDP was a result of hydrolysis of the RDP and generation of phosphorous acids. Exposure to harsh environments, such as storage outdoors or in hot, humid environments for extended periods of time can have a dramatic impact on the results of mechanical recycle of waste EEE. HIPS containing GreenArmor was virtually unaffected by these conditions and displayed excellent recyclability.

About Albemarle

Albemarle Corporation, headquartered in Baton Rouge, Louisiana, is a leading global developer, manufacturer, and marketer of highly-engineered specialty chemicals for consumer electronics, petroleum and petrochemical processing, transportation and industrial products, pharmaceuticals, agricultural products, and construction and packaging materials. The Company is committed to global sustainability and is advancing its eco practices and solutions in its three business segments, Polymer Solutions, Catalysts, and Fine Chemicals. Albemarle employs over 4,100 people and serves customers in approximately 100 countries.

About the author

Susan D. Landry, *Albemarle Corporation, Advisor, Fire Safety & Advocacy*

With over twenty-five years with Albemarle, Susan D. Landry serves as the company's Advisor, Fire Safety & Advocacy. In this role, Susan promotes the benefits of Albemarle's flame retardant products with a wide variety of stakeholders, particularly in the U.S. A respected expert on flame retardants, Susan has received fourteen patents related to these products and has presented numerous papers and presentations on flame retardants, with a particular emphasis on fire safety, regulatory, and recyclability. She recently authored a chapter ("Changing Chemical Regulations and Demands") in the American Chemical Society Book entitled, "Fire Retardancy of Polymeric Materials, 2nd Edition." Susan has served on an assessment panel in the Building & Fire Research Laboratory at the National Institute of Standards and Technology and she is a member of the SPE, SFPE, and SAE. Susan received a Bachelor of Science in Polymer Science from the University of Southern Mississippi in 1984.

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