D. Compatibilization/Compounding Evaluation of Recovered Polymers

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Objectives

- Evaluate the market opportunity for polymers recovered from shredder residue.
- Identify limitations associated with the reuse of the materials as recovered and determine the need for post-processing technology to upgrade the recovered materials to meet the requirements of the market.

Approach

- Specify standard protocols for material testing, content characterization, and performance properties.
- Determine properties of recovered polymers.
- Conduct blending and pelletizing trials of the recovered polymers.
- Conduct mold trials using recovered polymers.

Accomplishments

- Molded auto parts using recovered polypropylene/polyethylene (PP/PE).
- Conducted blending and pelletizing trial.
- Determined physical properties of PP/PE recovered from shredder residue.

- Found that PP/PE recovered by the Argonne process and the Salyp (sink/float) process and recovered in U.S. field trials exhibit equivalent physical properties that are reasonably consistent with those of many virgin PP formulations and co-polymers.
- Compiled a database of physical properties of virgin polymers for comparison with the physical properties of recovered plastics.
- Established a test protocol for material testing, content characterization, and physical properties testing of polymeric materials.

Future Direction

- Continue physical properties testing of recovered polymers.
- Evaluate the market potential for clean mixed plastics streams recovered from shredder residue.
- Update the database of properties of recovered polymers vis-à-vis general purpose virgin polymers.
- Identify candidate automotive applications for recovered polymers.
- Conduct more blending, pelletizing, compounding, and mold trials by using recovered polymers.

Summary

The objectives of this project are (1) to characterize the properties of potentially recyclable automotive materials and (2) to confirm the technical and economic feasibility of using those materials in value-added applications.

The project will initially focus on establishing the properties of polymeric materials that are recovered as part of the Post-Shred Materials Recovery Technology Development and Demonstration project (see report 7.E).

Regardless of the effectiveness of any automotive materials recovery technology, the materials that will be recovered will be, on average, at least 10 to 15 years old. In this project, the performance properties of recovered polymers will be compared vis-à-vis new or virgin materials to establish a database of the properties of recovered automotive polymers. At present, there are few data about the physical properties of polymers recovered from postconsumer durable goods. Absent such data, it is unlikely that sustainable applications for recycled materials will be either identified or developed.

Physical properties testing has been conducted by Midland Compounding, Inc. Midland also conducts composition testing, the results of which are compared with the results of compositional analysis done on recovered materials by Argonne.

Blending and pelletizing of the PP/PE recovered from shredder residue by Argonne has been tested by Palmer Plastics, Inc. More blending and compounding tests will be done, as required, to achieve the desired performance properties of the recovered materials for target applications.

Mold trials using the recovered PP/PE were also done by MGV Enterprises. More molding tests are planned to confirm the technical and economic feasibility of using recycled polymers in specific applications.

Three additional companies — Collins and Aikman Corporation, Enviro-Plas Corporation, and Mayco Plastics, Inc. — have agreed to evaluate, compound, and run mold trials by using recovered materials, subject to the physical properties of the recovered materials.

Polymer Physical Properties and Materials Composition Analysis

Typically, 10-lb samples of recovered materials are used to define physical properties and to characterize the composition of the material.

To quantify the physical properties of the recovered material, a sample is extruded on a single-screw extruder, melt screened through a 40-mesh screen, molded into American Society for Testing and Materials (ASTM) test bars and plaques, and tested. The molded parts and a random selection of regrind

chips from each sample are evaluated for material identification by using infrared spectroscopy.

Physical properties that are measured for each sample include the following:

- Melt flow rate (MFR),
- Izod impact,
- Flexural modulus,
- Tensile strength at yield,
- Tensile strength at rupture,
- Elongation at yield,
- Elongation at rupture,
- Deflection temperature under load (DTUL),
- Gardner impact, and
- Specific gravity (SG).

The physical properties of PP/PE recovered from different shredder residues by Argonne and by Salyp were determined for several samples. The results for the Argonne materials are given in Table 1. Properties of commercially-available PP and PE virgin resins and for PP from dismantled automobiles are presented in Table 2 for comparison. The Izod impact of the recovered material is about three times that of the virgin resins, while the tensile strength of the recovered material is lower than the tensile strength of the virgin resins by about 30%. This phenomenon may be attributed, at least in part, to the presence of thermoplastic olefins (TPO) and rubber in the recovered material, which act as impact modifiers. Recovered samples 8, 9, and 10 listed in Table 1 contained about 2% rubber, while samples 1 through 7 contained about 4% rubber.

The results for the more than 20 PP/PE samples recovered by Salyp from different European and U.S. shredder residues are given in Table 3. The properties of the Salyp-recovered PP/PE are equivalent to the properties of the Argonne-recovered PP/PE.

Polymer Physical Properties Database

A physical properties database has been compiled so that the physical properties of the recovered polymers can be compared with general purpose virgin polymers.

General purpose physical properties have been compiled for the following plastics:

- ABS,
- Nylon (6 cast, 6/6 extruded, 30% glass filled),
- PPO [polyphenylene oxide] (unfilled, 30% glass filled),
- Polycarbonate,
- Polyethylene, low-density polyethylene [LDPE], high-density polyethylene [HDPE], ultra-high-molecular-weight [UHMW] polyethylene,
- Polypropylene,
- Polystyrene (general purpose, high impact), and
- Polyvinyl chloride (PVC).

The Vehicle Recycling Partnership had previously compiled physical properties data on selected polymers that were recovered during the U.S. field trials (see ** in Table 2). These materials were recovered by disassembly. The data from these polymers will also be included in the database so that the physical properties of materials recovered by disassembly can be compared with those of materials that are recovered from post-shred operations.

Blending and Pelletizing of Recovered PP/PE

250 pounds of PP/PE recovered by Argonne were blended with 750 lbs. of supplemental PP copolymer regrind for 15 minutes. The blended material was then run through an extruder and pelletized. The general appearance of the final pellet was excellent (Figure 1). Properties of the recovered material used in blending and the properties of the regrind and of the resulting pellets are shown in Table 4. Standard pelletizing conditions were used. Barrel heats were set from 365°F at the rear barrel zone and increased progressively to 390°F at the front, with six heat zones in between. Screen-changer and breaker- plate heats were set at 405°F, and die heats were set at 395°F. Melt temperature was recorded as 460°F, and drive load and screw speed were set at 60% and 67.5% of the maximum values, respectively. Material output was recorded as 1,400 lb/h. Extra-fine screen packs were used (20/20/20/60/100/20 mesh screens) to remove impurities because this was the first time this material has been tried.

Table 1. Properties of PP/PE recovered by Argonne from different shredder residues.

Property	Sample 1	Sample 2	Sample 3	Sample 4	Sample 5	Sample 6	Sample 7	Sample 8	Sample 9	Sample 10	Average
MFR, g/10min, 230°C, 2.16 kg	10.5	14.9	7.7	10.1	11.4	7.2	8.7	7.2	8.7	7.2	9.4
Izod impact, ft-lb/in., 73°F	12.3	10.5	11.9	10.8	9	10.7	13.2	1.7	2.8	3.3	8.6
Flex mod., 1% secant, 1,000 psi	83	73	89	84	82	101	112	126	127	113	99.0
Tensile strength at yield, 1,000 psi	2.6	2.2	2.7	2.6	2.4	2.8	3.1	3.4	3.3	3.1	2.8
Tensile strength at rupture, 1,000 psi	0.8	1.2	2.1	1.9	1.4	2.5	2.0	3.1	3.1	2.9	2.1
Elongation at yield, %	23.0	20.8	21.1	22.8	20. 6	20. 6	17.1	**	**	**	24.3
Elongation at rupture, %	132	78	233	154	82	251	229	12	14	13	119.8
DTUL (F), at 66 psi	131	131	134	134	138	147	155	**	171	160	145
Gardner impact, 73°F, in.- lb	104	88	136	96	56	144	184	20	32	40	90.0
SG, g/cc	0.94	0.95	0.94	0.95	0.94	0.93	0.93	0.94	0.94	0.94	0.94

** Not tested

Table 2. Comparison of recovered PP/PE with commercial grades of PP & PE (Boedeker) (http://www.boedeker.com/mtable.htm), unless specified otherwise.

Property	PP-Homo Polymer	PP-Co Polymer	PP-FR	Dismantled PP**	Standard PP-Co	LDPE	HDPE
MFR, (g/10 min), 230°C	0.5-136*			17			
Izod impact, ft-lb/in.	1.9	7.5	0.65	1.8	0.7	No Break	3
Flex Mod, 1,000 psi	180	160	145	131.9	120	200	125
Tensile Strength, 1,000 psi	4.8	4.8	4.3	3.1	5.2	2.0	4.6
Elongation, %	12	23	28	18	600	600	900
DTUL (F), at 66 psi	210	173	106	136.5	210	110	--
SG, g/cc	0.905	0.897	0.988		0.90	0.92	0.95
Gardner impact, 73°F, in.- lb	0.9-22*						

* Data from http://www.ed-cam.com/materials/propylene_molded.asp. Ranges are for with and without additives.

** Gallmeyer, W.W.; Duranceau, C.M.; Williams, R.L.; and Winslow, G.R., USCAR U.S. Field Trial for Automotive Polymers Recycling, SAE paper # 2003-01-0645, 2003.

Table 3. Properties of PP/PE recovered by Salyp from different shredder residues.

Property	Salyp Data
MFR (g/10 min), 230°C	2.3–4.6
Izod impact (ft-lb/in.) 73°F	4.7–13.3
Flex mod., 1%, secant, 1,000 psi	81.7–116.5
Tensile strength at yield, 10,00 psi	2.4–2.9
Tensile strength at rupture, 1000 psi	2.2–2.8
Elongation at rupture, %	19–57
DTUL (F), at 66 psi	150–169
Gardner impact, 73°F, in.-lb	190–240
SG, g/cc	0.93

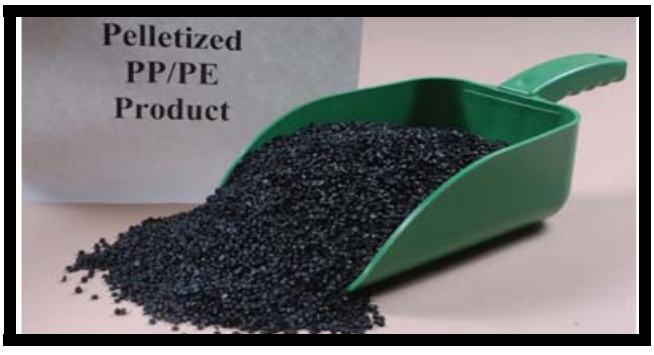

Figure 1. Pelletized PP/PE product recovered from shredder residue.

Table 4. Properties of recovered PP/PE when mixed with regrind.

Property	Argonne, As Recovered Sample 9 (see Table 1)	Regrind, As Is	Pelletized Blend
MFR (g/10 min), 230°C	8.7	3.1	9.2
Izod impact (ft-lb/in.) 73°F	2.8	13.6	10.4
Flex mod., 1%, secant, 1,000 psi	127	157	136
Tensile strength at yield, 1,000 psi	3.3	3.7	3.4
Tensile strength at rupture, 1,000 psi	3.1	2.9	2.3
Elongation at rupture, %	14	125	57
DTUL (F), at 66 psi	171	197	176
Gardner impact, 73°F, in.-lb	32	>320	132
SG, g/cc	0.94	0.91	0.92

In addition, while screen changes are typically performed at pressure differences between 500 psi and 1,000 psi, in this test, changes were performed when the pressure exceeded 500 psi to safeguard against puncturing a screen pack and losing material. Because extra-fine screen packs were used in the test, screen changes were required approximately every five minutes. The results indicated that the recovered PP/PE can be blended with other olefinic regrind and pelletized by using standard processes and equipment.

Mold Trials

Three types of auto parts were molded by MGV Enterprises by using Argonne-recovered PP/PE from shredder residue: knee bolsters, battery trays, and steering column covers (Figure 2). A standard molding machine was used in these trails (Figure 3). No changes to the standard conditions were required to run the recovered material. The limited testing done on the recovered PP/PE fraction shows that quality products, including auto parts, may be produced from the recovered materials. Additives and/or modifiers may be added to meet the specifications of some products.

Recovered Rubber/Plastics Material

A mixed-rubber fraction with about 20% by weight mixed plastics was recovered. A sample of the recovered material was sent for testing by the "TireCycle" process used for recycling rubber. Preliminary tests done on the recovered material indicated that it may be suitable for making construction products, such as roofing shingles. The presence of the plastics in the mixed-rubber material appeared to improve its overall properties, especially its stiffness.

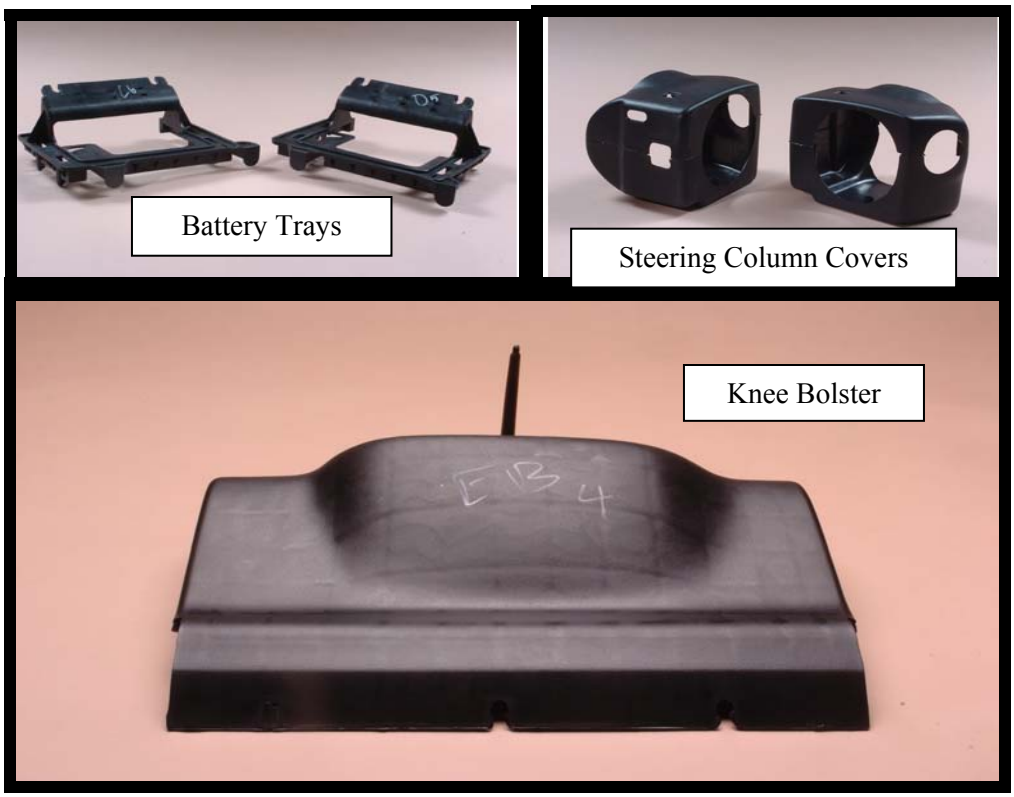

Figure 2. Auto parts molded from PP/PE recovered from shredder residue.

Figure 3. Standard molding machine used in molding auto parts using recovered PP/PE.