Designing with Plastics: Considering Part Recyclability and the Use of Recycled Materials

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It is a widely shared view that economic development will not be sustainable unless industry embarks on more innovative and proactive approaches to corporate environmental stewardship. "Green" product realization strategies—such as design for recycling (DFR)—and the increased use of recycled materials in the manufacture of new products are viewed as crucial components of such an approach. AT&T's design and engineering community is active in both fields. DFR is introduced as part of a broader design for environment (DFE) program. In addition, there are ambitious initiatives to find suitable internal uses for plastics recyclate, which AT&T's material reclamation organizations have produced from scrapped telephone housings for many years. These two programs are symbiotic: The greater the number of products designed for recycling, the greater the amount of high-value materials that can be readily recovered from them at the end of their useful lives. In turn, the higher the quality of the recycled materials, the easier to recycle those materials into new products. This paper describes strategies for DFR applicable to plastic parts and discusses two initial applications of post-consumer recycled plastics in new AT&T products.

Introduction

The design of recyclable products and the use of recycled materials constitute major product realization objectives in the emerging field of environmentally conscious design.[1-4] From technical and economic perspectives, design for recycling (DFR) will make comprehensive recycling of all types of products easier in the future. (See Panel 1 for definitions of abbreviations, acronyms, and terms.) Using recycled materials in the manufacture of new products reduces the consumption of virgin materials, which is a prerequisite for sustainable development and economic growth. The trend towards designing recyclable products and using recycled materials has also been stimulated by voluntary and legislated product take-back initiatives emerging worldwide, and by the potential savings to be derived from a well-executed recycling program.

AT&T is not new to the world of product take-back and recycling. Since sometime before its divestiture in 1984, AT&T has been operating a significant internal product take-back and material reclamation infrastructure to recover precious, ferrous, and nonferrous metals and plastics from scrapped equipment. In recent years, the recovery of plastics has focused primarily on producing post-consumer acrylonitrile butadiene styrene (ABS) recyclate from scrapped telephone housings. (ABS has been the predominant resin used for molding telephone housings for many years.) Except for a period of time following the oil shortage in the 1970s, when AT&T researchers briefly explored internal ABS recycling,[5] plastics recovered from scrapped products generally have been sold on the outside. Recently, however, AT&T has renewed its efforts to find uses for its recycled plastics internally.

The prerequisites for a successful company-internal plastics recycling program include the availability of large quantities of clean, good-quality plastics recyclate at competitive prices. Plastics recyclate is produced by shredding product components made of thermoplastic materials. Two major factors determine the purity, quality, and usability of the recyclate, namely, the original design of the plastic parts from which it is derived, and the abilities of the recyclate production process to remove impurities or foreign materials from the recyclate. In recent years, extensive progress has been made in removing impurities. No significant problems were encountered in recent molding trials with AT&T's post-consumer ABS recyclate, even though the material is now derived from parts contaminated with paints and labels. But how much better might the material be if plastic parts were designed with eventual recycling in mind, and if recycling inhibitors were consciously designed out of products?

This paper discusses the degree of DFR that designers can achieve and how recycled ABS can be used in new products. DFR is important because it sets the stage for more comprehensive recycling of products in the future. The closer the properties of the recyclate come to matching those of the virgin material, the easier it will be to implement closed-loop recycling. Thus, designers should keep in mind the product end of life and attempt to make products in general, and major plastic parts in particular, as recyclable as possible. They should also explore opportunities for reusing the ABS recyclate available now. While AT&T's current post-consumer recyclate is not a substitute for virgin material in most instances, applications exist where it is suitable, and where its use offers attractive savings. Parts recyclability and the use of recycled materials both deserve the designer's serious consideration.

Panel 1. Abbreviations, Acronyms, and Terms

ABS—acrylonitrile butadiene styrene
DFE—design for environment
DFR—design for recycling
DTUL—deflection temperature under load
HB—horizontal burn, the lowest UL flammability rating for plastics
ISO—International Organization for Standardization
psi—pounds per square inch
UL—Underwriters Laboratories

Design for Recycling

Creating the best product end-of-life design solution is a challenge for a variety of reasons.[6] It is difficult to predict the eventual fate of a product. At one end of the spectrum of possible reuse or recycling scenarios is meticulous product disassembly, with subsequent cleaning and reuse of parts. At the other end is material recycling after product destruction by shredding and post-shred material separation. Yet another end-of-life fate is landfill disposal or incineration. Very likely, all of these scenarios will be encountered to varying degrees when a product is manufactured in large quantities. Thus, a designer should anticipate them all. Accordingly, his or her objectives should be to design products that:

- Can be readily disassembled and reassembled,
- Yield clean, easily obtainable recyclate when the product is shredded, and
- Do not contain toxic substances that might become harmful to the environment if they end up in a landfill or incinerator.

Because this paper focuses on DFR, only strategies that help achieve the first two objectives will be explored. More comprehensive information about these and other relevant design strategies is available to AT&T designers and engineers in DFE guidelines posted on the World Wide Web.

Design for Disassembly and Reassembly. The ability to disassemble a product nondestructively is an issue that affects the repair and possible reuse of certain product components. The relative merits of snaps versus screws are still being debated in the assembly and disassembly of enclosure parts. The use of snaps minimizes parts and promotes ease of assembly. However, an enclosure held together by snaps can be difficult to open. In fact, many telephone enclosures are damaged at AT&T Service Centers during the process of opening them. Thus, designers should carefully consider which types of joining mechanisms to use for large items such as enclosure parts. It is clearly advisable to minimize the use of screws, but using a minimal number of screws or other suitable quick-disconnect fasteners that facilitate simple, reliable product disassembly and

Table I. ISO-compliant plastic marking codes

Generic resin	Marking code
acrylonitrile butadiene styrene (ABS)	> ABS <*
polycarbonate (PC)	> PC <
polycarbonate-ABS blend	> PC+ABS <
polystyrene (PS)	> PS <
polyphenylene ether—polystyrene blend	> PPE+PS <
nylon 6	> PA6 <
nylon 6/6	> PA66 <
polypropylene	> PP <
30-percent glass-filled polybutylene terephthalate—polycarbonate blend	> (PBT+ PC)–GF30 <

*The symbols > < are used by the ISO as delimiters to indicate a plastics marking code.

reassembly is often advantageous. If screws cannot be used, snaps should be designed to allow the opening of an enclosure or removal of a part without causing any damage. And just in case a snap should break, redundant screw holes should be designed into parts. If enclosure parts were better designed for disassembly and reassembly, service and product reconditioning centers would require many fewer new enclosure parts to replace damaged ones.

Avoiding Recycling Inhibitors. Whether or not a product or its components have experienced reuse, at some point material recycling will become the only realistic and cost-effective recycling option. Applying DFR to plastic parts enables designers to ensure that uncontaminated recyclate can be readily produced from scrapped parts using automated size reduction and material separation processes. *Recycling inhibitors*—materials that contaminate the base resin and that are difficult to separate from the base plastic when the part is eventually turned into recyclate—should be avoided, including:

- Decorative paints,
- Metallic coatings (for decorative or shielding purposes),
- Paper and metallic labels,
- Adhesive or other permanent joints that involve a foreign material,
- Ink contamination, and
- Other polymeric materials in the product with the same specific gravity as the predominant plastic.

Avoiding recycling inhibitors allows the design of parts that, after shredding and post-shred material separation, yield material of a quality close to *pre-consumer regrind.* (The designation "pre-consumer" regrind is reserved for recyclate derived from uncontaminated molding scrap such as sprues, runners, and defective parts. Pre-consumer regrind is already being routinely recycled by blending it with virgin polymer and looping the blend back into molding operations. To differentiate between pre- and post-consumer materials, the term "regrind" is used in connection with "pre-consumer" and the term "recyclate" with "post-consumer" materials.) Because of other design requirements, designers may not always have the freedom to avoid all recycling inhibitors. They should, however, seriously explore design solutions that optimize the recyclability of their products within the constraints of other product or design requirements.

Marking Plastics Properly. The proper marking of plastic parts also contributes to product recyclability. This realization motivated AT&T to initiate the practice of marking plastic parts in accordance with the International Organization for Standardization (ISO)-based "AT&T Standard for Marking Plastic Parts."[7] Table I shows some specific marking examples for polymeric materials frequently specified by AT&T designers. The marking practice helps identify the generic polymeric species of major plastic parts recovered by non-AT&T product and material facilities. In many foreign markets AT&T will have to rely on independent networks of product recycling centers to discharge its product take-back and recycling obligations. Correctly marked parts will help non-AT&T affiliated recycling centers to properly process the products entrusted to them for recycling. Furthermore, environmental product specifications for electronic products promulgated by organizations such as the "Blue Angel" in Germany require that plastic parts weighing more than 25 grams be marked according to the applicable ISO standards. Physical designers should specify that all new plastic parts be marked by molding in or melt-implanting applicable resin identifier codes in a way that does not contaminate the marked parts.

Table II. Comparison of typical physical properties

Property	Virgin ABS resin	AT&T recyclate (pelletized)	AT&T recyclate (flake)
Melt flow index (grams/10 min)	6.0	6.0	6.0
Tensile strength @ yield (psi)	5,950	6,500	6,000
Tensile modulus (psi)	130,000		150,000
Flexural modulus (psi)	325,000		350,000
Elongation @ yield (percent)	6.0	2.5	5.0
Elongation @ break (percent)	24.0		5.0
Notched Izod @ 23°C (ft-lb/in)	6.5	1.0-2.0	1.0-2.0
DTUL* @ 264 psi (°F)	200	169	177
DTUL @ 66 psi (°F)	210	194	202
UL 94 flame rating	HB†	Not rated	Not rated

*Deflection temperature under load.

†Horizontal burn, the lowest UL flammability rating for plastics.

Use of Recycled Materials

DFR, which was discussed in the previous section, is not an end in itself, but rather a means to an end. The end is product recycling. The use of recycled materials in the manufacture of new products is a major life-cycle design imperative.[3] Recycling not only conserves virgin resources and avoids impacts generated in material extraction, refining, and processing, it also prevents still usable materials from ending up in landfills or incinerators.

The supply of recyclable materials retrievable from scrapped business and communications equipment is huge. It is estimated that the worldwide business and communications equipment industry currently consumes roughly one billion pounds of engineering plastics annually. And the pipeline is still being filled with products that eventually will have to be scuttled. Currently, only about one personal computer for every three sold is being scrapped. By the year 2005, however, one PC will be scrapped for every one being sold.[8] To simply dump all that discarded hardware into a landfill is not only irresponsible from an environmental perspective, it is also an unconscionable waste of valuable material resources. It is not surprising that product take-back laws are starting to emerge in some countries.

The recycling of materials retrieved from scrapped products, particularly materials such as plastics, is not a trivial matter, and certainly not simply a matter of passing product take-back laws. If recycled materials are not suitable for new product applications, they have little chance of being used. Plastics that are reused in electronic product applications must comply with a profusion of national and international product standards. Unfortunately for designers, recycled engineering plastics that comply with the required material specifications are still hard to obtain. In the future, when plastics with a certain amount of recycled material content and properties guaranteed by the compounder become commercially available, using recycled resin grades will entail the same procedure as using virgin resins today.

Currently, however, using recycled plastics is not as straightforward as using commercial virgin plastics. Because AT&T chooses to have many of its products listed by Underwriters Laboratories (UL), it is obligated to design products that comply with the UL end-product safety standards. Among other things, this entails using only UL-recognized plastic compounds for applications such as electronic enclosures. Unfortunately, virtually all UL-recognized plastic compounds available today are virgin compounds. Although this does not mean that "post-consumer" recycled plastics cannot be used at all, it does mean that equipment manufacturers need to:

- Enlist the help of a compounder in reconstituting a UL-recognized plastic compound with a significant recycled material fraction and agreed-upon specification,
- Work with UL directly on an approved recycled material qualification program, or
- Use recyclate for selected applications in which a UL-recognized resin is not explicitly required.

The first two options are a viable intermediate to longer-term approaches for implementing a comprehensive closed-loop plastics recycling program. The third option is the only one available as of the writing of this paper.

The physical, mechanical, and processing properties of recyclate are not only dependent on the material

Figure 1. (a) Scrapped telephone housings of various colors, which are processed into (b) a recyclate of multicolored flakes. When these are molded, they yield parts that are grey in color. (c) A standard plastic mounting panel, made from recyclate, with components of a PARTNER® communications system mounted on it. Compared to a plywood panel, the plastic panel reduces provisioning costs and intervals and is lighter and less expensive.

they are derived from, but also on the processing technology. Loss of properties can be minimized in recyclate that is produced under carefully controlled conditions using state-of-the-art technology.

Table II compares typical properties of virgin and 100-percent post-consumer ABS recyclate produced by AT&T today. AT&T recyclate is available in both flake and pelletized form. The Izod recyclate has a lower impact strength and is not UL rated. Because the flake is derived from scrapped telephone housings of different colors, as shown in Figure 1, the flake form recyclate is multi-colored; when it is molded or extruded, it yields parts that are grey. Thus, the pelletized recyclate is also grey, with color uniformity that varies from batch to batch. As a result, the recyclate is not suitable for appearance parts or applications requiring a high-impact-strength material. Nevertheless, designers should be able to identify selected applications for which it is perfectly adequate. Two examples of such applications are discussed in the sections that follow. In both cases, 100-percent recyclate was used, rather than a recyclate/virgin blend, making the cost of the piece parts significantly less expensive.

Wall Mount for MERLIN® and PARTNER® Communications Systems. Often, when a business communications system such as the MERLIN or PARTNER communications system is installed at a customer site, the installer has to custom make a mounting panel by cutting a plywood board to the required size and drilling mounting holes. Because this nonstandard procedure is time-consuming and expensive, a standard plastic mounting panel was designed.[9] This panel, which will become a standard part of the MERLIN and PARTNER hardware kit, allows both pre-assembly and testing of the system at a Pre-Assembly Work Center, and more rapid final installation at the customer site. Compared to the plywood panel, the plastic panel reduces provisioning costs and intervals and is lighter and less expensive.

Figure 1c shows this panel with components of a

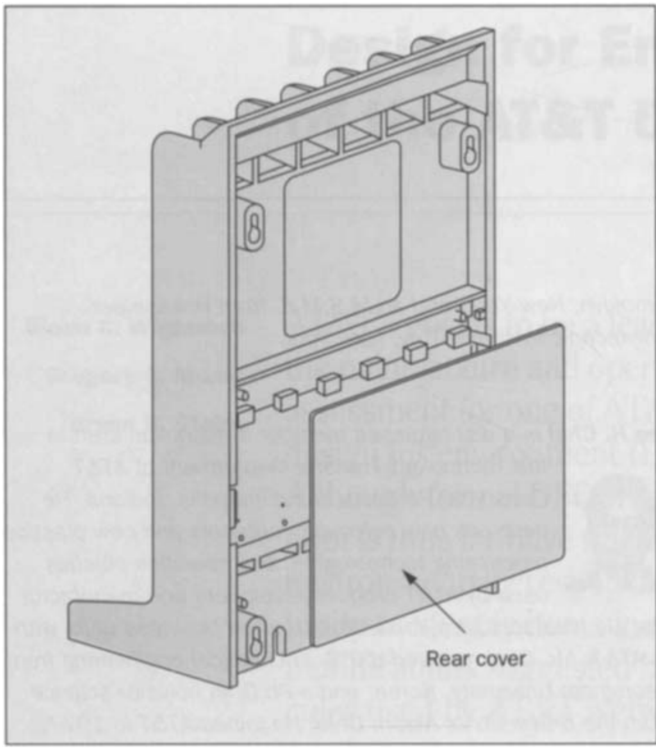

Figure 2. An assembly drawing showing the TransTalk™ 9000 carrier base station, including the rear cover, manufactured from 100-percent post-consumer recyclate.

PARTNER system mounted on it. It is a good example of a product that can be molded using 100-percent post-consumer ABS recyclate. Its color and surface quality are secondary issues because the panel is not considered an aesthetic part. Although no specific UL requirements apply to this part, because it serves neither as an enclosure nor an insulator, it was submitted to UL for a flammability test. In addition, to ascertain fitness for its intended use, the panel was subjected to environmental stress tests, aging tests, and loading and drop tests. It passed them all. Using post-consumer ABS recyclate to manufacture this panel also saved money, because the cost of ABS recyclate is only about one-third that of virgin ABS.

Rear Cover for the TransTalk™ 9000 Radio Base Station Carrier Assembly. The rear cover for the TransTalk 9000 radio base station carrier assembly is also made from 100-percent post-consumer recycled ABS. It is a simple, flat piece of 0.060-inch-thick die-cut plastic, the kind of part that rarely gets a second look. It was designed quickly, sent out for quotes, and placed into production. That might have been the end of this story; however, the TransTalk development program was under great pressure to control the cost of goods, so the use of post-consumer recycled ABS made great economic sense.

The requirements for the rear cover are not demanding, making it another good candidate for recycled ABS. Because the rear cover is not considered part of the enclosure, flammability is not an issue. There are also no structural concerns. The part covers exposed pins on the backplane and protects the user/installer from the sharp component leads, which can be a minor nuisance during handling and installation. Once the carrier is installed, the rear cover is rarely seen again. Final assembly of the TransTalk 9000 carrier takes place at the DENPORT South Facility in Shreveport, Louisiana. The backplane is attached to the carrier plastic, and then the rear cover is flexed into place and captured by features on the carrier. Figure 2 is an assembly drawing showing the TransTalk 9000 carrier, including its rear cover, manufactured from recyclate.

As the rear cover was being designed, preliminary drawings were made and sent out by purchasing for quotations. Purchasing received several quotes, suggesting different types of virgin materials, each of which costs about $1 per part. At that stage in the development another option was needed, and it came in the form of the cover die cut from a plastic sheet extruded from post-consumer ABS. The panel made from recycled material cost only about 11 cents. Both examples, the PARTNER mounting panel and the TransTalk 9000 carrier rear cover, demonstrate the savings that can be realized from using ABS recyclate.

Conclusion

Whatever experience has been gained to date in recycling engineering polymers from old computers and communications equipment suggests that engineering plastics are more recyclable than has been generally assumed in the past.[10] As a result, several large original equipment manufacturers are starting to seriously explore the merits of plastics recycling.[11,12] In AT&T's experience, to maximize the use of recycled plastics and derive the largest economic benefit from recycling efforts, products need to be designed for eventual recycling and the highest-value applications available for recycled materials need to be identified. These two objectives are interrelated. Keeping both of these objectives in the forefront will help AT&T to become a more competitive player in a world that increasingly requires products that are world class, not only in their applications, but also in their environmental attributes.

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