Recycling of Blends of Acrylonitrile–Butadiene–Styrene (ABS) and Polyamide

Xiaodong Liu,[1] Antal Boldizar,[1] Mikael Rigdahl,[1] Hans Bertilsson[2]

[1]*Department of Polymeric Materials, Chalmers University of Technology, SE-412 96 Gothenburg, Sweden*
[2]*Artimplant AB, Hulda Mellgrens gata 5, SE-412 32 Västra Frölunda, Sweden*

ABSTRACT: The aim of this work is to evaluate routes to upgrade recycled engineering plastics, especially mixed plastics with acrylonitrile–butadiene–styrene copolymers (ABS) as the major component. A core-shell impact modifier was successfully used to improve the impact strength of blends of ABS and ABS/polycarbonate (PC) blends recycled from the automotive industry. However, the presence of other immiscible components like polyamide (PA), even in small amounts, can lead to a deterioration in the overall properties of the blends. A styrene–maleic anhydride (SMA) copolymer and other commercial polymer blends were used to promote the compatibilization of ABS and PA. The core-shell impact modifier was again found to be an efficient additive with regard to the impact strength of the compatibilized ABS/PA blends. The results obtained with fresh material blends were quite promising. However, in blends of recycled ABS and glass-fiber-reinforced PA, the impact strength did not exhibit the desired behavior. The presence of poorly bonded glass fibers in the blend matrix was the probable reason for the poor impact strength compared with that of a blend of recycled ABS and mineral-filled PA. Although functionalized triblock rubbers (SEBS–MA) can substantially enhance the impact strength of PA, they did not improve the impact strength of ABS/PA blends because the miscibility with ABS is poor. The possibilities of using commercial polymer blends to compatibilize otherwise incompatible polymer mixtures were also explored giving promising results. © 2002 Wiley Periodicals, Inc. J Appl Polym Sci 86: 2535–2543, 2002

Key words: polymers; blends; recycling; compatibilization; toughness; polyamides; acrylonitrile–butadiene–styrene (ABS); impact modifiers

INTRODUCTION

The automotive industry constitutes a substantial resource for recycled engineering plastics. Today, ~75 wt % of each end-of-life vehicle (ELV) is recycled, mainly the metals. The goal for automotive recycling is that 95 % of each ELV should be recycled in the year 2015.[1] The remaining material, after sorting out metals, is called automotive shredder residues (ASR), which contains rubbers, glass, fabrics, plastics, and contaminates. The primary destination of ASR has been landfill. However, environmental concern and reductions in available landfill capacity have promoted the recycling of plastics from scrapped automobiles. The proportion of plastics in the total weight of a car was ~10–13% in 1990; this figure continues to rise and could approach 15–20% in 2000.[2,3] Among the recycled plastics, the engineering plastics represent a higher value and have better mechanical properties than commodity plastics, and thus they are potentially more worthwhile to recycle. Many of the engineering plastics have densities in the range $1.05–1.15 \times$ $10^3 \, \text{kg/m}^3$, and it is thus possible to extract them from ASR by a simple density separation.

The mechanical recycling of commingled plastics often gives a material with unfavorable mechanical properties, especially poor toughness. This result is because most polymers are incompatible with each other. Acrylonitrile–butadiene–styrene copolymers (ABS) constitute the largest fraction of the recycled engineering plastics. Some engineering plastics, such as poly(methyl methacrylate) (PMMA) and polycarbonate (PC), are compatible with ABS, whereas others, such as polyamide (PA), are not. ABS is relatively inexpensive and has a high impact strength at low temperatures. The major drawback of ABS is its poor chemical resistance. Crystalline engineering plastics like PA have excellent solvent resistance, but their notch sensitivity sometimes limits their use. In this work, the possibility of blending ABS with PA is investigated, and attempts are made to maintain the advantages of both materials.

The compatibilization of two different polymers is often carried out in the presence of a block or graft copolymer, with blocks interacting with each of the components. Such a block or graft copolymer can be prepared prior to blending and added into a blend, or it can be generated *in situ* during blending. However, the former approach requires a specially developed

Material	Description	Density, kg/m^3	Melt volume-flow rate, cm^3/10 min	Source
PA6	Ultramide B3	1130	130 (275°C, 5 kg)	BASF
ABS	Commercial grade	1050	14 (220°C, 10 kg)	—
SAN25	Commercial grade	1030	22 (220°C, 10 kg)	—
SEBS-MA 1901	Kraton FG1901X, functionalized block copolymer	—	—	Shell
SEBS-MA 1924	Kraton FG1924X, functionalized block copolymer	—	—	Shell
SMA25	Polystyrene with 25 % maleic anhydride	1070	—	—
Cadon	SMA/ABS blend with 20 % of glass fibre, Cadon G2320	1230	—	Bayer
Triax 1120	Triax 1120, ABS/PA6 blend with a compatibilizer	1060	4.5 (250°C, 5 kg)	Bayer
Triax 1220	Triax 1220, ABS/PA6 blend with a compatibilizer	1050	2 (250°C, 5 kg)	Bayer

block copolymer and the compatibilization efficiency is governed by a diffusion process across the interface. Engineering plastics (except ABS), such as polyamide and polyesters, are often synthesised via condensation polymerization, which means that they contain functional chain-end groups that offer a possibility for further chemical reaction. Compatibilization of incompatible but reactive polymers can be achieved by *in situ* compatibilization. In blends with ABS as the majority phase, the compatibilizer should be miscible with or compatible with ABS and react with the other component. For example, SMA is a styrene–maleic anhydride copolymer that is miscible with the styrene–acrylonitrile copolymer (SAN) phase in ABS provided that the acrylonitrile content and maleic anhydride content do not differ too much (within the so-called "miscibility window"). The maleic anhydride group can react with PA and lead to compatibilization of the ABS/PA/SMA blend.[4–8] The reaction products are block or graft copolymers with SMA and polyamide blocks, and such copolymers can function as compatibilizers. It should be mentioned that industrial interest has also been shown in the compatibilization of ABS/PA blends with various *in situ* compatibilizers.[9–16]

Another problem associated with commingled plastic recyclates is that the additives or fillers in one polymer might cause unexpected structural and mechanical property changes in the other components, which can then lead to a deterioration of the entire material. Being a semicrystalline plastic with a low glass transition temperature, the polyamide used in the automotive industry is often glass fiber reinforced or mineral filled to maintain a high stiffness at elevated temperatures. The glass fibers may be the reason for the reduced impact strength when such a PA-grade is blended with ABS.[17,18]

It has earlier[19] been noted that SMA with 8 and 14% maleic anhydride (SMA8 and SMA14, respectively) are not very effective compatibilizers with regard to improving the impact strength of the ABS/PA6 blends. Other compatibilizers have therefore been

used here, including a styrene–maleic anhydride copolymer containing 25% maleic anhydride (SMA25), a commercial SMA/ABS blend (Cadon™), and a commercial ABS/PA blend (Triax™). SMA25 is miscible with the matrix of the ABS used here, styrene–acrylonitrile copolymer with 25% acrylonitrile (SAN25),[4] and is capable of reacting with polyamide at processing temperatures >170°C. An SMA–PA block copolymer, which is a compatibilizer for the ABS/PA6 blends, will then be generated *in situ*. Triax™ ABS/PA blend contains an effective compatibilizer for the otherwise incompatible components ABS and PA. Thus, the Triax™ blend has the potential of being compatible with both PA and ABS.

Fresh as well as recycled ABS/PA blends were prepared with the addition of the SMA25 compatibilizer and a core-shell rubber impact modifier. SMA25 is an efficient emulsifier that reduces the PA domain size, and the core-shell impact modifier is able to improve the impact strength of ABS/PA blends dramatically.[20] SMA25 has also been found to significantly improve the interfacial adhesion in ABS/PA sandwich moldings.[21] The effect of SMA25 on the mechanical performance of fresh ABS/PA blends has been described in detail by Liu et al.[20]. Only the major findings are therefore reported here, the major focus being on recycled blends. The commercial ABS/SMA and ABS/PA blends also exhibited a compatibilizing effect on the ABS/PA blends. SEBS–MA rubbers can react with PA and then act as an impact modifier for recycled PA. However, because of the poor miscibility of ABS and SEBS–MA, it was not a suitable impact modifier for the ABS/PA blends.

MATERIALS

Fresh materials

Some characteristics of the fresh materials are summarized in Table I. ABS is a general-purpose copolymer of injection molding grade. SAN25 is a commercial grade styrene–acrylonitrile copolymer containing 25%

acrylonitrile. Ultramide B3 (PA6 B3) is a rather low molecular mass injection molding grade of polyamide 6. The all-acrylic core-shell impact modifier used was Paraloid EXL 3300, with a poly(methyl methacrylate) (PMMA) shell and an acrylic rubber core. The particle diameter of this impact modifier was 0.3 μm.

Two thermoplastic elastomers with maleic anhydride functionality were used to modify polyamide. Kraton FG1901X (SEBS–MA1901) is a triblock copolymer (71% hydrogenated butadiene midblock resembling an ethylene/butene copolymer and 29% styrene end-blocks), in which the mid-block is functionalized with 2% maleic anhydride. Kraton FG1924X (SEBS–MA1924) is a linear triblock copolymer based on styrene and ethylene/butylene, with a polystyrene content of 13%, functionalized with 1% maleic anhydride.

Maleic anhydride-containing copolymers were used as compatibilizers. The SMA25 is a polystyrene copolymerized with 25% maleic anhydride. Cadon G2320 is a SMA/ABS blend with 20% glass fibers. Triax 1120 and Triax 1220 are both ABS/PA6 blends. Both of these blends contain compatibilizers that can enhance the interaction between PA and ABS.

Recycled materials

The recycled ABS (Re ABS) was taken from the interior of dismantled Volvo 700 cars. The recycled polyamide materials were of two different grades containing glass fibers (coded Re PA-1) and mineral fillers (coded Re PA-2), respectively. Re PA 1 was a mixture of PA6 and PA66 with glass fibers from several parts of disassembled Volvo cars (e.g., seat position adjustment knobs, paddles, and coolant intakes). Re PA-2 was from the mineral-filled polyamide wheel cover with a coating for attractive surface appearance. The wheel covers were milled into small pieces ~2–4 mm in size, but no effort was made to remove the coating. Recycled ABS/PC blends [coded Re (ABS/PC)] were taken from the interior of dismantled Volvo cars. Recycled PMMA (coded Re PMMA) was from the tail-light of dismantled cars. All recycled materials were washed, dried, and then milled into particles 2–4 mm in size.

All above-mentioned fresh and recycled materials were dried before processing: polyamide materials at 120°C for at least 6 h and the other materials at 100°C for at least 6 h.

EXPERIMENTAL

Brabender mixing

For the morphological study, blends were prepared in a 50-mL capacity Brabender batch mixer equipped with a standard blade. The blending was carried out at 250°C and 40 rpm for 10 min.

Twin screw extrusion and injection molding

For the mechanical testing, blends were produced with a twin-screw extruder, Werner & Pfleiderer ZSK 30 M 9/2. The processing temperature was 250°C (except where specified) and the screw speed was 200 rpm. The extrudates were pelletized with a granulator. Test specimens were injection molded with an ENGEL 330/80 injection molding machine with melt and mold temperatures of 250 and 50°C, respectively.

Mechanical properties

The mechanical properties were evaluated at 22 ± 1°C and 55 ± 5% relative humidity. The tensile properties were measured with a Zwick UTM 1455 at a crosshead speed of 5 mm/min (strain rate 0.0014 s^{-1}). The average values of at least five specimens are reported. The notched Charpy impact strength was determined with a Frank KMO 79 impact tester according to ISO 179 specimen type 2. The average values of at least 10 specimens are reported. The typical deviations from the average values were <10% for tensile modulus and yield strength, and <30% for elongation at break and impact strength.

The J_C value represents the energy required to initiate crack growth and was determined in accordance with ASTM standard D6086-96 and E813-89 using a three-point bend fixture in an universal tensile test machine (Instron model 1193) at a crosshead speed of 2 mm/min. The details of this technique have been described previously.[19,20]

Scanning electron microscopy (SEM)

The morphology of the fracture surfaces of the specimens was investigated with a Digital Scanning Electron Microscope Zeiss DSM 940A. The surfaces were coated with a thin gold layer, ~50 Å thick.

RESULTS AND DISCUSSION

Mechanical properties

Fresh ABS/PA blends with SMA25 as compatibilizer and SEBS–MA as impact modifier

The mechanical properties of the fresh ABS grade and of the fresh blends are listed in Tables II and III. Because ABS and PA are not miscible, a simple mixture of ABS and PA gives a material with poor mechanical properties. In a previous work,[20] it was shown that the ABS/PA6/SMA25 80/20/2 blend had a higher modulus, yield strength, and elongation at break than the pure ABS grade. (Note that 80/20/2 means that 2 parts of SMA25 have been added to 100 parts the ABS/PA 80/20 blend.) However, the Charpy impact strength of the blend was only half that of the

TABLE II
Mechanical Properties of Fresh Materials

Composition	Tensile modulus, GPa	Yield strength, MPa	Elongation at break, %	Impact strength, notched kJ/m^2	J_C kJ/m^2
ABS	2.3	40	14	13.0	8.9
Triax 1120	1.2	26	>100	NB[a]	27.6
Triax 1220	1.1	26	>100	NB	NA[b]

[a] NB: not broken or not completely broken. [b] NA: Not available.

pure ABS. Because, as shown later, SMA25 can significantly reduce the size of dispersed PA domains in the SAN25 matrix, the same effect was expected in the ABS/PA blends. However, a reduction in domain size does not necessarily give better mechanical properties than those of the major component in a blend, especially not in the case of the impact strength, as noted here. The addition of 10 parts EXL3300 core-shell impact modifier to this blend doubled the impact strength up to 13.5 kJ/m^2 (see also, Liu et al.[20]), but the tensile modulus and yield strength decreased as expected (Table III).

The triblock copolymer SEBS–MA 1901 was used in the present work as a toughening agent to be compared with EXL3300. The impact strength of the blend with 10 parts SEBS–MA 1901 (i.e., ABS/PA6/SMA25/SEBS–MA 1901, 80/20/2/10) was not substantially greater than that of the blend without SEBS–MA1901. The J_C value also remained essentially the same, but the elongation at break increased to 55%. Although SEBS–MA is capable of toughening PA,[22–27] it thus had no significant influence on the impact strength of the ABS/PA blend compared with the effect of EXL3300. The reason for this result may be the poor affinity between ABS and SEBS–MA, as discussed later.

Recycled ABS/PA blends

The successful compatibilization and toughening of the fresh ABS/PA blends[20] made it tempting to use the same technique for recycled materials. The results of the mechanical evaluation are summarized in Table IV. The Re ABS/Re PA-1 80/20 blend with 10 parts EXL3300 and 2 parts SMA25 exhibited a higher mod-

ulus and higher yield strength than Re ABS, but the material had a very poor impact strength (3.2 kJ/m^2) and elongation at break (4%). These values are slightly better than the corresponding results for the similar blend containing SMA8 (styrene–maleic anhydride with 8 wt % maleic anhydride) as the compatibilizer,[19] but much lower than those noted for Re ABS and Re PA-1. The probable reason for this result is that the glass fibers present in the PA phase in this case do not bond well to the ABS matrix. Unbonded glass fibers may act as sites for stress concentrations and initiation points for cracks to develop during the impact. Another blend of similar composition, but with Re PA-2 (containing mineral filler) instead of Re PA-1, was also prepared, and a higher notched impact strength (7.0 kJ/m^2) was noted. The elongation at break was 7%. Both these values were higher than those of the Re ABS/Re PA-1 blends and these results also imply that it is the glass fibers in the PA phase that dramatically lower the mechanical properties of Re ABS/Re PA 1 blends. The mineral filler had much less influence on the impact strength.

Several engineering plastics from dismantled cars were also blended to study the possibility of using mixed engineering thermoplastics without sorting them. The mixture consisted of four recycled materials; Re ABS, Re ABS/PC, Re PMMA, and Re PA-1. The composition of the mixture was chosen to correspond to the proportions of these materials used in the Volvo 700 series automobiles. The blend used was 100 parts of Re ABS/Re (ABS/PC)/Re PMMA/Re PA-1, in proportions of 40/40/10/10, with 2 parts SMA25 and 5 parts EXL3300 rubber. Because ABS, PC, and PMMA are miscible or compatible, compatibilization is required only for the PA phase with the other three

TABLE III
Mechanical Properties of Fresh ABS/PA Blends

Composition	Tensile modulus, GPa	Yield strength, MPa	Elongation at break, %	Impact strength, notched kJ/m^2	J_C kJ/m^2
ABS/PA6/SMA25 80/20/2	2.5	49	27	6.5	11.1
ABS/PA6/SMA25/EXL3300 80/20/2/10	2.2	43	32	13.5	9.3
ABS/PA6/SMA25/SEBS-MA1901 80/20/2/5	2.3	43	55	7.0	10.8
ABS/Triax 1220 80/20	2.2	42	37	10.8	9.0
ABS/PA6/Triax 1120 70/20/10	2.2	40	>90	13.2	9.4
ABS/PA6/CadonG2320/EXL3300 80/20/4/5	2.2	39	64	8.6	10.8

TABLE IV
Mechanical Properties of Recycled ABS, PA, and Their Blends

Composition	Tensile modulus, GPa	Yield strength, MPa	Elongation at break, %	Impact strength, notched kJ/m^2	J_C kJ/m^2
Re ABS	2.4	39.2	12	7.4	5.1
Re PA-1	8.6	134.0	3	5.0	N/A
Re PA-2	3.1	55.3	7	9.0	N/A
Re ABS/Re PA-1 80/20 + 5 parts SMA8 + 5 parts MBS^a [19]	3.5	53.0	3	2.5	N/A
Re ABS/Re PA-1 80/20 + 2 parts SMA25 + 5 parts EXL3300	2.9	44.3	4	3.2	N/A
Re ABS/Re PA-2 80/20 + 2 parts SMA25 + 5 parts EXL3300	2.1	38.4	7	7.0	3.6
Re ABS/Re (ABS/PC)/Re PMMA/Re PA-1 40/40/10/10 + 2 parts SMA8 + 5 parts MBS [18]	2.7	49.3	10	6.6	6.8
Re ABS/Re (ABS/PC)/Re PMMA/Re PA-1 40/40/10/10 + 2 parts SMA25 + 5 parts EXL3300	2.7	47.3	12	5.7	9.4
Re PA-1/SEBS-MA1901 85/15 [19]	5.7	78.0	9	13.1	11.0
Re PA-1/SEBS-MA1924 85/15	4.7	71.0	10	16.5	14.8
RE PA-2/SEBS-MA1924 82/18	2.0	38.0	33	19.9	19.5

^{a} MBS is a core-shell impact modifier with a PMMA shell and a rubber core. Its trade name is Paraloid EXL3647 from Rohm & Haas.

components. SMA is miscible or compatible with ABS, PC, and PMMA and it can react, as already mentioned, with PA. The impact strength of this blend was 5.7 kJ/m^2 (Table IV) and, again, it was noted that the glass fibers were not well bonded to the matrix. However, the impact strength of this blend was substantially higher than that of the Re ABS/Re PA1 blend. This result is partly due to the lower content of the noncompatible PA phase (10%) and hence the lower content of unbonded glass fibers. Another reason is the presence of the inherently tough polycarbonate. A similar blend, but with SMA8 as compatibilizer, has been reported on earlier.[18] SMA25, which is a better compatibilizer for these ABS/PA blends, did not however give a greater impact strength than SMA8. This result was somewhat unexpected, but, on the other hand, the elongation at break and the J_C value increased.

Blends of Re PA with reactive rubber

It has been shown[22–27] that the SEBS–MA1901 rubber is an efficient toughening agent for polyamide, especially for PA66 and mixtures of PA6 and PA66. In the case of PA 6,[28] the highest impact strength was obtained when the SEBS–MA rubber was diluted with nonmaleated SEBS-rubber. In other words, the SEBS–MA is more efficient when the overall functionality of the rubber phase is relatively low. In one of these systems, the maximum impact strength was obtained when the average functional group content was 0.3–0.5 %.[28] Two kinds of functional rubbers, SEBS–MA1901 and SEBS–MA1924, were used in this study.

The former is a triblock copolymer with 2% MA and the latter is a triblock copolymer with 1% MA. The two different grades of reinforced PA from the automotive industry were blended with SEBS–MA1924. When 15% SEBS–MA1924 was added at a processing temperature of 260°C, the impact strength of Re PA-1 increased to 16.5 kJ/m^2, compared with 5.0 kJ/m^2 for the unmodified Re PA-1 and 13.1 kJ/m^2 for Re PA-1/SEBS–MA1901 85/15 blend.[19] The elongation at break also increased from 3% for the unmodified Re PA-1 to 10% for the 15% SEBS–MA1924 modified blend. The low functional rubber SEBS–MA1924 thus exhibited a better toughening effect than SEBS–MA1901 (see also Majumdar et al.[24]). When 18% of SEBS–MA1924 was added to Re PA-2 at a processing temperature of 260°C, the impact strength increased to 19.9 kJ/m^2. The modulus and yield strength decreased, however, as expected. These results indicate that both the SEBS–MA rubbers can be used as impact modifiers for recycled PA although they do not appear to be very efficient impact modifiers for ABS/PA-blends.

Using commercial polymer blends as compatibilizers

Many engineering plastic blends actually contain potential compatibilizers for immiscible polymers, which might be an advantage in the mechanical recycling of plastics. In an ideal situation, no external compatibilizer would be required if the recycled plastic mixture contained a component that can act as such a compatibilizer. In this work, two commercial blends were chosen to compatibilize the immiscible ABS/PA blends.
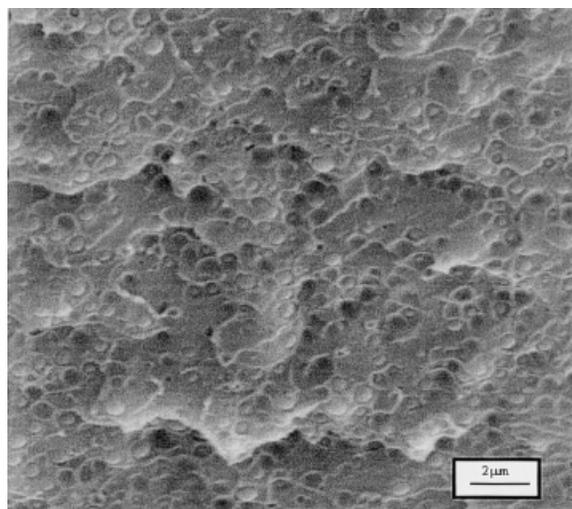
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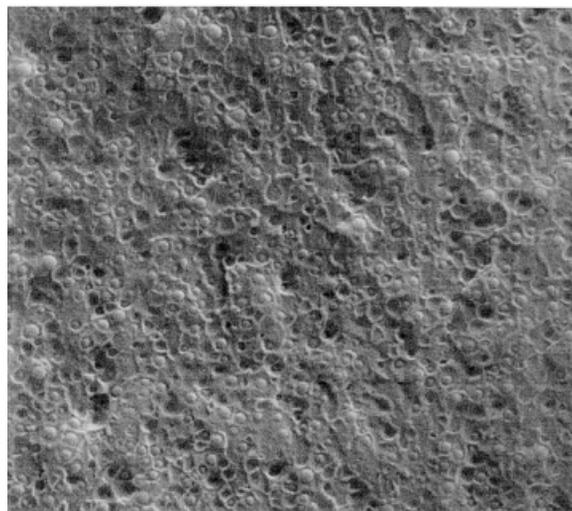
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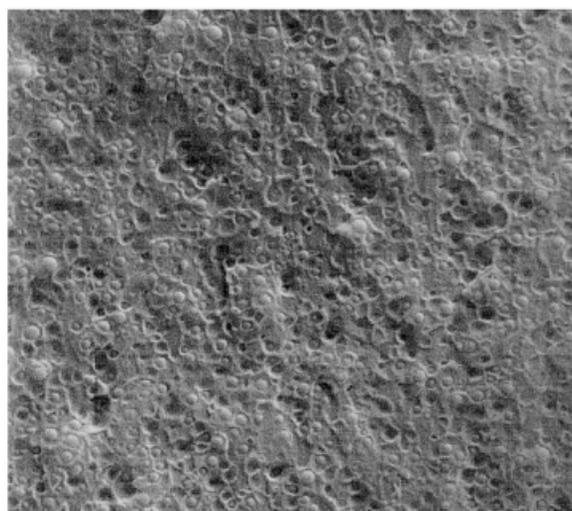
(C)

Commercial SMA25/ABS blends with or without glass fibers are used in the automotive industry to replace ABS in certain applications because of their higher heat deflection temperature (HDT). These blends will in turn appear in the recycled plastic stream in coming years. Because they are compatible with ABS and are able to react with PA, such materials can be incorporated into ABS/PA mixtures as compatibilizers. The Cadon™ G2320 with 20% glass fibers was used here for that purpose, and the ABS/PA6/Cadon G2300/EXL3300 80/20/4/5 blend had reasonably good mechanical properties (Table III). The elongation at break and J_C value, which represent ductility and toughness at low deformation rates, respectively, were better than those of pure ABS. However, the Charpy impact strength was only 8.6 kJ/m^2, which is lower than that of the pure ABS. The reason for this result could be twofold; the glass fibers may act as stress concentration sites and the amount of EXL3300 was relatively low. The products Triax 1120 and Triax 1220 contain ABS, PA6, and compatibilizer. It is expected that such blends are compatible with ABS and PA and thus capable of compatibilizing the ABS/PA mixture. The ABS/Triax 1220 80/20 blend displayed a 20% lower impact strength than pure ABS, but the J_C value was comparable to that of pure ABS (Table III). Moreover, the elongation at break was 37%, which is more than twice that of ABS. The ABS/PA6/Triax1120 70/20/10 blend had better mechanical properties than the ABS/Triax 1220 blend, and the J_C value was 15% higher than that of ABS. The Charpy impact strength was, however, the same as that of ABS. The elongation at break was >90%, in contrast to the value of 14% for ABS.

Morphology

### Morphology of SAN/PA blends with SMA25 as compatibilizer

SMA25 is an effective compatibilizer for ABS/PA blends, the morphology of which has been discussed elsewhere.[19,20] To understand further the effect of SMA25 as a compatibilizer for ABS/PA6 blends, the matrix of ABS, SAN25, was mixed with PA6. SAN25/PA6 (80/20) blends with 2, 4, and 7 parts of SMA25 were prepared using the Brabender batch mixer. The blends were cryofractured and the fracture surfaces were studied by SEM. All these blends exhibited dispersed particle/matrix structures. With only 2 parts of SMA25, the dispersed PA6 particle size decreased from 2 μm to <0.5 μm see Figure 1a). When 4 parts of

Figure 1 SEM micrographs of SAN25/PA6 blends with different amounts of SMA: (a) blend of SAN25/PA6/SMA25 80/20/2; (b) blend of SAN25/PA6/SMA25 80/20/4; and (c) SAN25/PA6/SMA25 80/20/7. The same magnification was used in all micrographs.

SMA25 were incorporated, the particle size decreased to <0.3 μm (Figure 1b). No further significant reduction in the particle size was observed, however, in the blend with 7 parts of SMA25 (Figure 1c).

Morphology of the SAN25/SEBS–MA 80/20 blend

To study the compatibility between ABS and SEBS–MA, a SAN25/SEBS–MA1901 80/20 blend was prepared. This blend formed a coarse structure with elongated domains together with a large amount of small particles (see Figure 2a). The replacement of 5%
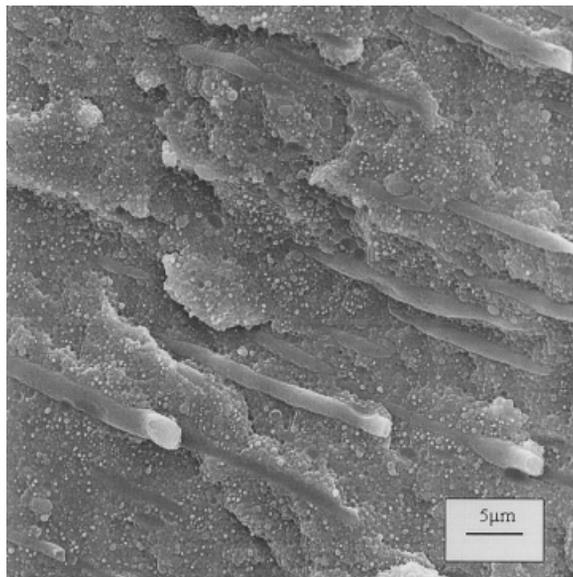
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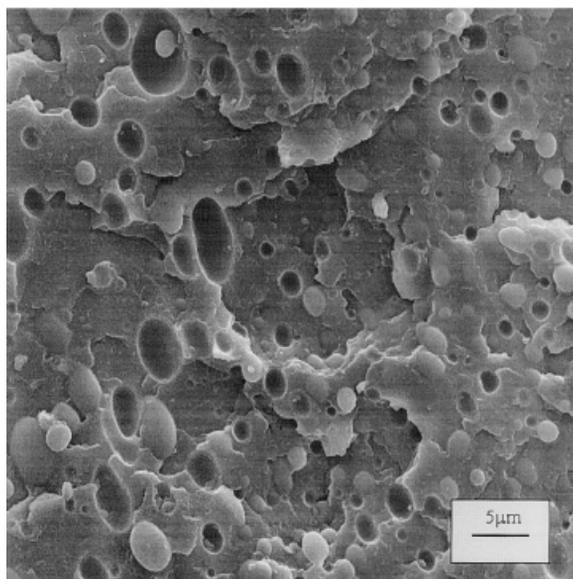
(B)

Figure 2 Morphology of SAN/SEB5-MA 1901 blends showing the unfavorable affinity: (a) SAN/SEB5-MA 1901 80/20; and (b) SAN/SEB5-MA 1901/SMA25 80/15/5.
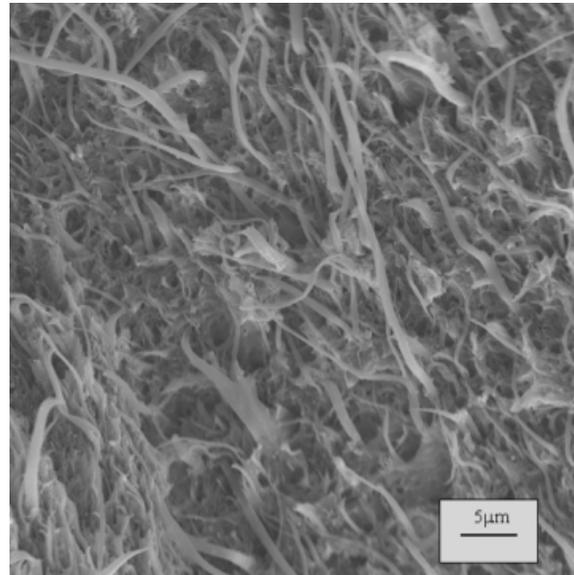
Figure 3 SEM micrograph showing the fibril-like structure in the fracture surface of the *J*-integral test specimen for the blend ABS/PA6/Triax 1120 70/20/10.

SEBS–MA 1901 with 5% SMA25 had a pronounced effect on the morphology of the blend. There were then no longer any elongated domains or small particles present; the dispersed domains appeared larger, up to 5 μm, and were not perfectly spherical (see Figure 2b). The micrographs of these two blends indicated that the affinity between SAN25 and SEBS–MA1901 was not good, with or without SMA25. therefore, SEBS–MA is not a very suitable impact modifier for the ABS blends, as was indicated by the just reported mechanical performance of these blends containing ABS and SEBS–MA.

Morphology of the ABS/PA6/Triax1120 blend

The addition of 10% commercial ABS/PA blend Triax 1120 had a compatibilizing effect on the ABS/PA6 70/20 blend, as indicated by the small PA-domain size in the cryofractured surfaces, the cross-section diameter being <1 μm. (This micrograph is not shown here.) On the other hand, the fracture surface obtained at a low deformation rate (*J*-integral method) exhibited a fibril-like structure (see Figure 3). This kind of structure was previously observed with ABS/PA, ABS/PBT, and ABS/PET blends and the mechanism for generating such fibril structures has been discussed previously.[19,20] In brief, the PA phase initially had a certain continuity; it was then elongated and pulled out from the ABS phase.

Morphology of the ABS/PA/Cadon blend

Cadon G2320 is an ABS/SMA blend with 20% glass fibers. The *J*-integral specimen fracture surface of the
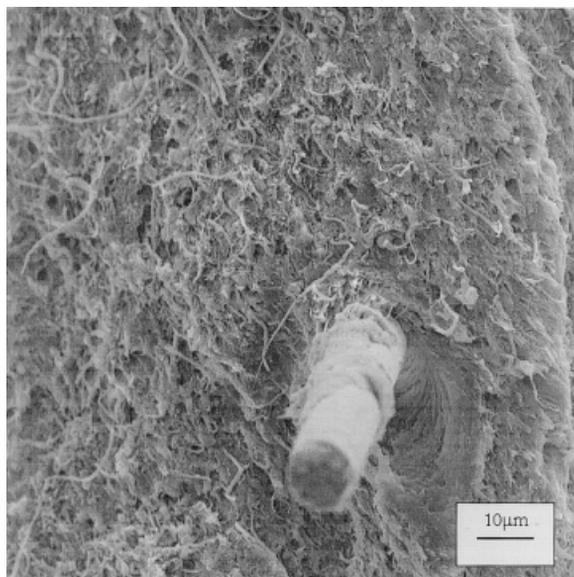
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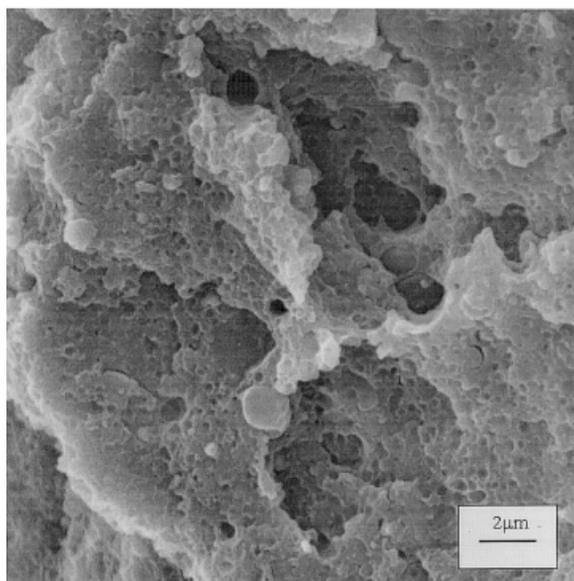
(B)

Figure 4 SEM micrograph of the ABS/PA6 80/20 blend with five parts of EXL 3000 and four parts of Cadon G2320: (a) the well-bonded glass fiber and the fibril-like structure in the fracture surface of the *J*-integral test specimens (low deformation rate fracture); and (b) the "particle-matrix"-like structure in the fracture surface of the impact test specimens (high deformation rate fracture).

ABS/PA6 80/20 blends with 5 parts of EXL3300 and 4 parts of Cadon G2320 also revealed fibril structures (see Figure 4a). As is evident in the same micrograph, the glass fibers seem to be well bonded to the matrix because the matrix material is seen to adhere to the pulled-out fiber surfaces. In the impact fracture surface, the PA-domain appeared to be <0.5 μm (see Figure 4b), indicating a compatibilizing effect of this Cadon grade.

Recycled materials

In the recycled ABS/PA blends that contained glass-fiber-reinforced nylon, the glass fibers did not bond to the matrix very well. This poor bonding is probably the reason for the somewhat inferior mechanical properties of these blends. One example is shown in Figure 5. Although a fibril structure was observed in many *J*-integral test specimens of fresh ABS/PA blends, it was not seen in the recycled ABS/PA blends. In the Re PA-2 with mineral fillers, the size of mineral filler is between 2 and 10 μm, the major part being in the range 2–5 μm, judging from the SEM micrographs. (SEM micrographs are not shown here.) Fracture at a low deformation rate involved debonding of mineral particles, whereas no such debonding was observed at higher deformation rates (impact testing).

CONCLUSIONS

1. A reactive compatibilizer based on the styrene–maleic anhydride copolymer with 25% maleic anhydride significantly decreased the PA domain size in SAN and probably also enhanced the adhesion between SAN and PA, as reported elsewhere.[21] The mechanical properties of ABS/PA can be upgraded with small amounts of such a compatibilizer, and still further with a core-shell impact modifier. The commercial blends that contain SMA can also act as compatibilizers for ABS/PA blends. It was found that a commercial ABS/PA blend was capable of compatibilizing the blend.
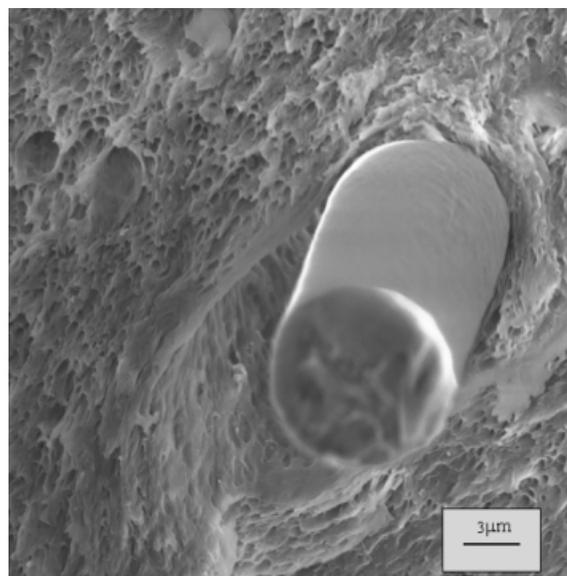

Figure 5 SEM micrograph of fracture surface of a *J*-integral test specimen from the Re ABS/Re PA1 80/20 blend with four parts SMA25 and 10 parts EXL 3300.

2. The same strategy with recycled materials did not produce the desired result. The primary difference was that the impact strength was quite low. In the Re ABS/Re PA-1 blends, the presence of glass fibers in the Re PA-1 phase, which were not well bonded to the matrix, is probably the reason for the low impact strength. However, with the mineral-filler-containing polyamide, the Re ABS/Re PA-2 blend displayed a greater impact strength.

3. The functionalized thermoplastic rubbers SEBS–MA were capable of improving the impact strength of recycled polyamide quite markedly. The low maleic anhydride content rubber produced the better result. However, it is not a suitable impact modifier for ABS/PA-blends because of its poor compatibility with ABS.

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