Recycling of Mixed Automotive Plastics

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Abstract: Mixed plastics from junked autos were homogenized by milling or extrusion, modified by addition of low-molecular-weight low-melt-viscosity polymers, and processed by compression or injection molding. Properties were comparable with high-density polyethylene and common building panel materials.

INTRODUCTION

Modern democracies began with promises of liberty, equality, and pursuit of happiness. In their second century, the invention of the automobile contributed increasingly toward the material achievement of these goals. In their third century, increasing auto production may actually begin to overwhelm us (Table 1).

Table 1. Motor Vehicle Production in 1995 [1]

Country	Number
United States	11,985,091
Japan	10,195,536
Germany	4,667,364
France	3,474,705
South Korea	2,526,400
Canada	2,417,176
Spain	2,333,787
Others	12,262,606
Total	49,862,665

The average life of an auto is about ten years. At the end of its useful life, it goes to the junkyard. A few spare parts are recycled directly for repair of similar models, but the vast majority of old cars are just junk. They are ground in a "shredder" and the metals are separated and recycled at full economic value. The remainder, called

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"light fluff," is bulldozed to the back of the junkyard, where it accumulates and becomes an ecological and economic liability.

Typical analysis of light fluff indicates a mixture of plastics and other materials (Table 2).

Table 2. Composition of 1980 Clean Light Fluff [2]

Ingredient	Wt.-%
Fibrous (Cloth, Paper, Wood)	71
Rubber	6
Polyurethane Foam	6
Polyolefins	5
Poly(vinyl chloride)	5
Acrylonitrile-Butadiene-Styrene	3
Reinforced Polyester	3
Other	1
Total	100

Plastics have increasingly been replacing metals because of easier processability, more versatile design, lighter weight = lower fuel consumption, and corrosion resistance (Table 3).

Table 3. Plastics as Percentage of Total Auto [3]

Year	Wt.-%
1965	2
1995	12
2000 (projected)	20+

This has led to growing interest in recycling of automotive plastics. Germany has taken the lead in mandating increasing recycling of such materials, 20% in 1996, 50% in 2000 [4]. Large parts and expensive engineering plastics may possibly be separated as individual plastic materials and recycled at considerable economic value [5-7]. For the most part, however, disassembly and separation are too difficult to be economic (Table 4).

Table 4. Disassembly Time of Auto Parts [8]

Part	Weight, kg	Time, s
Armrest	0.14	30
Battery Clip	0.05	25
Battery Tray	0.45	30
Body Side Molding	1.59	30
Console	1.63	220
Door Trim Panel	1.36	200
Engine Splash Shield	0.91	135
Fan Shroud	1.72	132
Fender Line	1.04	105
Fuel Tank Shield	2.22	100
Garnish Molding	0.14	14
Grill Opening	4.08	280
Luggage Compartment Trim	0.54	23
Radiator End Tank	0.36	105
Window Washer Reservoir	0.54	28
Wiring Harness	4.54	48

This raises the question whether the total mixed plastics, or more probably the total light fluff, can be recycled economically into useful materials.

MILLING AND COMPRESSION MOLDING

Light fluff was improved by washing and density fractionation to remove metals, glass, and dirt [2]. Light fluff collected from junkyards in 1980 (from autos manufactured, on the average, in 1970) could be cleaned and compacted into structural panels by low-pressure compression molding. Light fluff for 1990 was predicted by comparing market analyses for 1970 vs. 1980 [9] and adding virgin resins to 1980 fluff to simulate model 1990 fluff (Table 5).

Mastication on two-roll mills (Table 6) and compression molding at increasing pressures (Table 7) improved properties considerably.

Table 5. Model 1990 Clean Light Fluff [2]

Ingredient	Wt.-%
Fibrous (Cloth, Paper, Wood)	41
Polyolefins	14
Polyurethane Foam	12
Reinforced Polyester	10
Poly(vinyl chloride)	9
Acrylonitrile-Butadiene-Styrene	6
Rubber	4
Nylon	3
Poly(methyl methacrylate)	1
Total	100

Table 6. Mill Mastication of 1980 Clean Light Fluff [10]

Milling Time, min	Flexural Modulus, MPa	Flexural Strength, MPa
0	97	1.41
2.5	103	1.54
5	331	2.76
10	572	3.60
20	579	4.83

Table 7. Compression Molding of Clean Light Fluff [11]

Clean Light Fluff	Molding Pressure MPa	Flexural Modulus MPa	Flexural Strength MPa	Notched Izod Impact Strength, J/cm
1980	3.45	—	—	—
1980	6.90	351.7	6.62	0.48
1980	10.34	358.6	6.83	0.48
1980	13.79	372.4	6.83	0.53
1980	17.24	379.3	6.97	0.64
1980	19.16	393.1	6.97	0.75
1990	3.45	—	—	—
1990	6.90	510.3	8.76	0.64
1990	10.34	572.4	8.90	0.70
1990	13.79	613.8	9.10	0.75
1990	17.24	675.9	9.72	0.75
1990	19.16	744.8	12.69	0.91

ADDITION OF LOW-MOLECULAR-WEIGHT LOW-MELT-VISCOSITY RESINS

While these end properties were promising, the low thermoplastic content and the high fiber content gave melt viscosities too high for conventional thermoplastic processing. To increase melt flow up to the conventional range for extrusion (MFI = 1) and injection molding (MFI = 5), 5-20 parts per hundred resin (phr) of low-molecular-weight low-melt-viscosity resins were added (Table 8).

This permitted conventional plastics processing (Table 9).

Table 8. Effect of Low-Molecular-Weight Low-Melt-Viscosity Resins on Melt Flow Index [12]

Additive	Amount, phr	MFI, g/10 min
None	0	0.1
Polyflo Atactic Polypropylene	5	1.1
	10	2.5
	20	8.5
Eastman N-34 Polyethylene Wax (MW 2900)	5	0.5
	10	1.0
	20	6.5
Union Carbide PCL-300 Polycaprolactone	5	0.6
	10	1.1
	20	2.7
Union Carbide GERS-1077 LLDPE (MFI 100)	5	0.4
	10	0.7
	20	2.4

Table 9. Effect of Melt Flow Improvers on Properties [12]

Additive	Amount phr	Flexural Modulus MPa	Flexural Strength MPa	Notched Izod Impact Strength, J/cm
None	0	621	5.44	0.32
Atactic PP	5	483	4.55	0.32
	10	283	3.31	0.37
	20	240	3.31	0.53
PE Wax	5	566	3.68	0.32
	10	414	2.93	0.27
	20	393	3.74	0.27

One injection-molding run gave properties far superior to all the compression-molding studies, and comparable with virgin high-density polyethylene and commercial building panels (Table 10).

Table 10. Comparison of Compression vs. Injection Molding [12]

	Flexural Modulus MPa	Flexural Strength MPa	Notched Izod Impact Strength, J/cm
Process			
Compression	807	10.2	0.37
Injection	1724	19.1	0.32
Commercial Controls			
HD-PE	786	15.3	2.73
Particle Board	—	10.1	0.50
Masonite	—	6.60	0.80

Table 11. Clean Light Fluff Model for 2003

Polymer	Wt.-%
Polyurethane Foam	10.8
Polyurethane Reaction Injection-Molded	10.8
Polypropylene	15.2
Acrylonitrile-Butadiene-Styrene	13.2
Nylon 6	10.2
High-Density Polyethylene	5.0
Linear Low-Density Polyethylene	5.0
Reinforced Unsaturated Polyester	7.8
Plasticized Poly(vinyl chloride)	4.8
Poly(methyl methacrylate)	3.2
Polycarbonate	2.9
Poly(butylene terephthalate)	2.8
Styrene/Maleic Anhydride	2.5
Poly(phenylene ether) + Polystyrene	2.4
Polyacetal	1.6
Poly(ether-ester) Elastomer	1.1
Phenol-Formaldehyde	0.7
Total	100

MIXED PLASTICS MODEL FOR 2003

In the most recent study, 1993 market analysis [13] was used to prepare a model of the mixed plastics expected in clean light fluff in the year 2003 (Table 11). The mixed polymers were homogenized by mill mastication or melt extrusion in single or twin-screw extruders, and injection-molded to form standard test specimens. Compared with the older studies, the increased thermoplastic content, and absence of fibrous impurities, gave reasonable thermoplastic processability without the need for low-molecular-weight low-melt-viscosity additives (Table 12).

Table 12. Melt Flow Index of Extrusion-Blended Mixed Plastics

Extrusion-Blending Temperature, °C	210	220	230
Melt Flow Index, g/10 min	0.36	0.38	0.46

On the other hand, the absence of large amounts of fibrous impurities, normally found in real light fluff, deprived the moldings of their reinforcing value, giving somewhat lower properties (Table 13).

Table 13. Properties of Mixed Automotive Plastics Expected in 2003

Property	Model 2003 Mixture (Table 11)	Modified Mixture
Melt Flow Index, g/10 min	0.4	—
Tensile Modulus, MPa	773	1075
Tensile Strength, MPa	8	14
Flexural Modulus, MPa	987	1084
Flexural Strength, MPa	17	26
Notched Izod Impact Strength, J/cm	0.2	0.2
Heat Deflection Temperature, °C	50	—
Volume Resistivity, 10^{14} Ω cm	3.2	—
Water Absorption, %	0.7	—
Gasoline Absorption, %	17	—

Here again, addition of 5 % of a low-molecular-weight low-melt-viscosity resin, Eastman Epolene E-43 emulsifiable polyolefin wax (MW = 4500), as modifier increased melt flow and final properties considerably.

CONCLUSION

Thus the obvious next step should be to return to the evaluation of real light fluff from auto junkyards, to see how much these model studies can help to understand and utilize the real mixture of recycled automotive plastics.

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