

ENVIRONMENTAL IMPACT OF FILLERS

This chapter contains information on the flammability and fire resistance of filled materials. It also covers the recycling of filled materials.¹⁻²¹

12.1 DEFINITIONS

The terms listed in Table 12.1 are commonly used in the evaluation of materials flammability and to describe the impact of fire.

Table 12.1 Definitions

Term	Definition	Unit
Char yield	Total residue of combustion (carbonaceous char + inorganic material)	wt%
Ignition time	The period required for the entire surface to burn with a sustained, luminous flame	s
Peak rate of heat release	Maximum heat released during a fire (peak value of heat release). This value expresses maximum intensity of fire	kW/m ²
Rate of heat release	Average value of heat release rate during a specified period of time. This value correlates with heat release in a room burn situation where all of the material is not ignited at the same time	kW/m ²
Specific extinction area	The measure of smoke obscuration averaged over the whole test period	m ² /kg
Fire performance index	The ratio of ignition time to peak rate of heat release. This parameter relates to the time to flashover in a full scale fire	m ² s/kW
Smoke parameter	The product of the average specific extinction area and the peak rate of heat release. This parameter indicates the amount of smoke generated	MW/kg
Limiting oxygen index	The minimum concentration of oxygen in an oxygen-nitrogen atmosphere required to initiate and support a flame for more than 3 min	% O ₂
Propensity of flashover	The ratio of ignition time to peak rate of heat release. It is the same as fire performance index	m ² s/kW
Smoke production rate	A product of the average mass loss rate and the average specific extinction area	m ² /s
CO yield	Carbon monoxide yield per unit surface area	g/m ²

Fillers can play an important role in limiting the flammability of materials and in reducing the damage and injuries caused by fires.

12.2 LIMITING OXYGEN INDEX

Table 12.2 Limiting oxygen index (LOI) for different materials

Filler		Polymer	LOI		Refs.
Type	Conc. wt%		control	with filler	
Al(OH) ₃	20/30/40/50	Flexible PVC	25.7	28.5/29.9/30.3/33.5	15
Al(OH) ₃	33/50/60	PMMA		19.8/22.1/27.5	27
Al(OH) ₃	55	EVA	18.5	30.5	27
Anthracite	40/50/60	HDPE	18.7	20.2/21.7/22.5	12
Apatite	1-4	Wood pulp	17	23	2
Ca ₂ B ₆ O ₁₁	18.4/42.1/48.8	EPM	18.3	19.0/20.9/21.9	9
CaCO ₃	55	EVA	18.3	29.0	27
Glass fiber	30	PEI	47	32	18
Glass fiber	30	PEEK	19	43	18
Glass fiber	30	PES	38	41	18
Mg(OH) ₂	40/50/60	EVA	17.5	22.0/24.0/42.5	10
Mg(OH) ₂	55	EVA	18.5	38.5	27
Mg(OH) ₂	20/30/40/50	Flexible PVC	25.7	28.6/30.4/31.3/30.3	15
Mg(OH) ₂	60	PA-6	24.1	51.3-70.0*	7,25
Mg(OH) ₂	60	PA-66	26.5	45.9-57.4*	7,25
Mg(OH) ₂	10/30/60	PP	17.5	18/20/27	29
Sb ₂ O ₃	2.5/5	Polyester	26.8	39.2/42.9	14
Talc	10/30/60	PP	17.5	17.5/21/20.5	29

*depending on particle size (the smaller the particle the higher the LOI)

Limiting oxygen index (LOI) is the parameter most frequently used to characterize the improvements in fire retardancy.^{1-3,6-7,9-16,18-19,22-30} Table 12.2 gives a summary of data obtained for various fillers. The data in Table 12.2 show that even the addition of very common and inexpensive fillers such as calcium carbonate or talc increases the LOI value. From the data presented, Sb₂O₃ and Mg(OH)₂ are the most efficient in increasing LOI.

Figure 12.1 shows the effect of increasing the concentration of different fillers on the LOI value.⁷ Mg(OH)₂ produces a much larger effect than the other fillers listed but high concentrations are required to obtain a substantial effect on LOI.

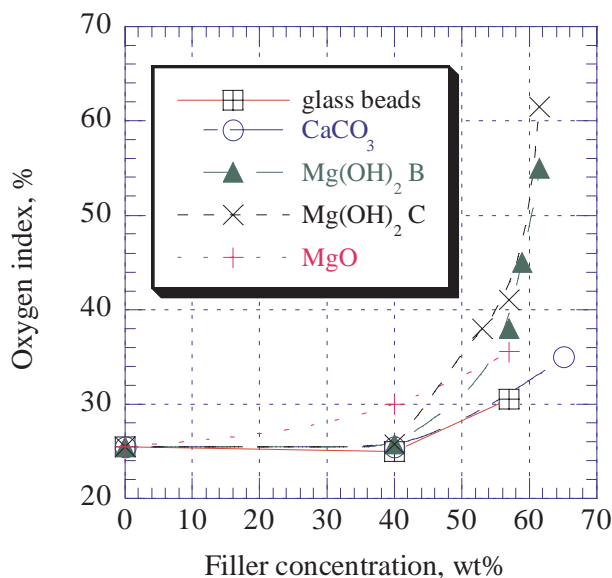


Figure 12.1. Limiting oxygen index vs. filler concentration in PA-66. [Adapted, by permission, from Hornsby P R, Wang J, Jackson G, Rothon R N, Wilkinson G, Cosstick K, Antec '94. Conference Proceedings, San Francisco, Ca., 1st-5th May 1994, Vol. III, 2834-9.]

The performance of fillers can be improved by the use of combinations of organic fire retardants and mineral fillers.^{11,14,22} Substantially better results can be obtained by the surface coating of fillers. When zinc hydroxystannate was used to coat $\text{Al}(\text{OH})_3$ and $\text{Mg}(\text{OH})_2$, the LOI value was improved by 18 to 35% for $\text{Mg}(\text{OH})_2$ and 28 to 36% for $\text{Al}(\text{OH})_3$.¹⁵

12.3 IGNITION AND FLAME SPREAD RATE

Autoignition temperature, ignition time, and flame spread rate are influenced by fillers.^{8,9,11,13,14,15,27,29,31} The ignition times of various filled systems are given in Table 12.3. The data in Table 12.3 show that the results are not very precise and depend on the method used. $\text{Al}(\text{OH})_3$ performed best.

Autoignition tests are performed either at constant temperature (the specimen is held at 430°C and the time to ignition is measured),²⁹ or at varying temperatures (the specimen is placed in a 100% oxygen environment and the temperature at which ignition occurs is recorded),³¹ or in varying oxygen concentrations.⁸ Figure 12.2 shows the effect of carbon black on the autoignition temperature of a fluoroelastomer. Carbon black increases the autoignition temperature because it forms stable oxides on the charred surface.³¹

Autoignition of epoxy and phenolic composites with glass fiber, aramid and graphite was affected by the oxygen concentration to a limited degree.⁸ But with epoxy composites, neither fiber type nor concentration of oxygen had an effect on the autoignition time (~50 s). In phenolic composites, the fiber type affected

Table 12.3. Ignition time

Filler, wt%		Polymer	Ignition time, s		Refs.
Type	Concentration		control	with filler	
Al(OH) ₃	55	EVA	<2	20	27
Al(OH) ₃	20/30/40/50	PVC flexible	16	22/31/78/43	15
Glass beads	55	EVA	<2	<2	27
Mg(OH) ₂	20/30/40/50	PVC flexible	16	16/11/27/21	15
Mg(OH) ₂	55	EVA	<2	20	27
Precipitated CaCO ₃	55	EVA	<2	<2	27
Sb ₂ O ₃	2.5/5	Polyester	25	22/24	14

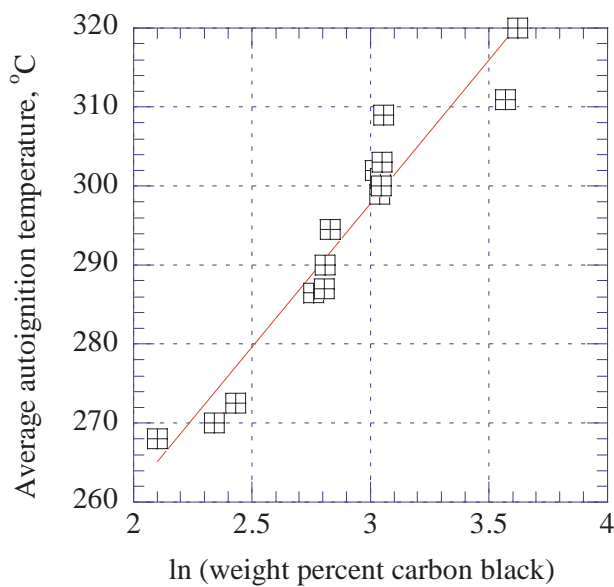


Figure 12.2. Autoignition temperature of fluoroelastomer vs. carbon black concentration. [Adapted, by permission, from Fu-Yu Hsieh, Bryan C J, Pedley M D, *Fire & Mat.*, **18**, No.6, 1994, 389-91.]

autoignition time more than oxygen concentration. Graphite-reinforced phenolic composites were the most stable.

Figures 12.3 and 12.4 show the effect of talc and Mg(OH)₂ in polypropylene on autoignition time and temperature. Mg(OH)₂ improved autoignition time more than did talc.²⁹ Mg(OH)₂ had some effect on autoignition temperature.

Flame propagation is expressed by length (cm),⁸ rate (mm/s),^{8,9,11,13} and flame persistence (s).^{9,11,13} Figure 12.5 shows data on the rate of flame spread for a PP-PE

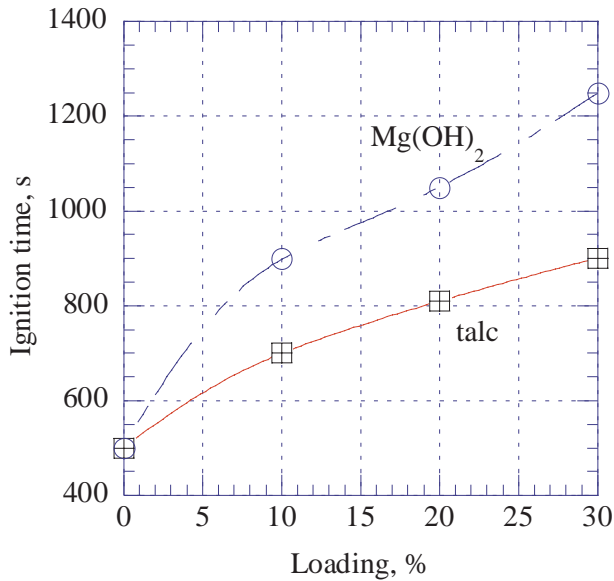


Figure 12.3. Autoignition time measured @ 430°C for PP containing talc and $Mg(OH)_2$. [Data from Costa L, Camino G, Bertelli G, Borsini G, *Fire & Mat.*, **19**, No.3, 1995, 133-42.]

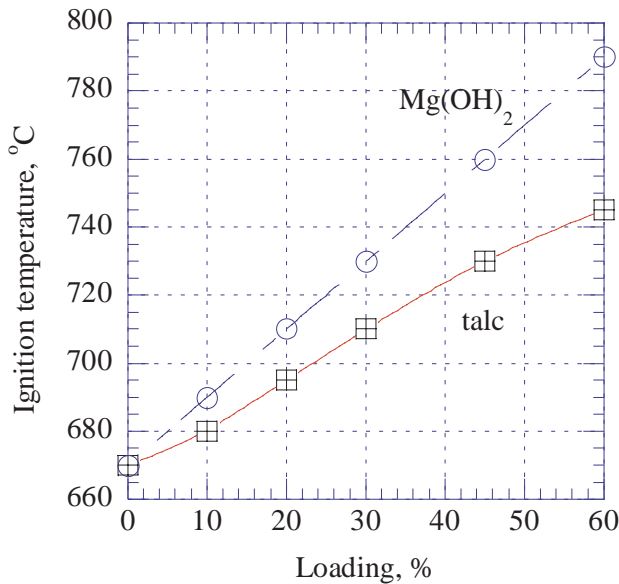


Figure 12.4. Autoignition temperature measured by glow wire test for PP containing talc and $Mg(OH)_2$. [Data from Costa L, Camino G, Bertelli G, Borsini G, *Fire & Mat.*, **19**, No.3, 1995, 133-42.]

copolymer filled with Portacarb (a mixture of hydromagnesite and huntite).^{9,11,13} The addition of filler has reduced the rate of flame spread in an effective manner.

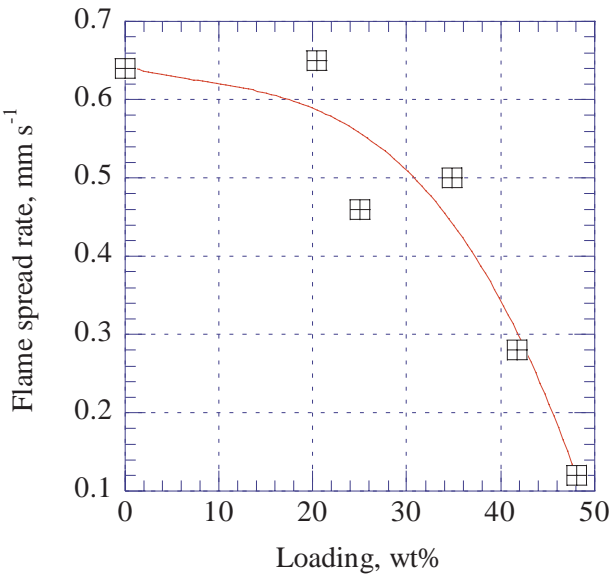


Figure 12.5. Rate of flame spread vs. Portacarb concentration. [Data from Toure B, Lopez Cuesta J M, Gaudon P, Benhassaine A, Crespy A, *Polym. Degradat. Stabil.*, **53**, No.3, 1996, 371-9.]

Table 12.4. Heat transmission rate

Filler, wt%		Polymer	Heat transmission rate, kW/m ²		Refs.
Type	Concentration		control	with filler	
Al(OH) ₃ *	30/40/50	PVC flexible	290	173/120/104	15
Al(OH) ₃	30/40/50	PVC flexible	232	133/98/80	15
fumed silica**	5/8	ABS	1500	900/800	23
fumed silica**	3/5	PET	1600	400/320	23
fumed silica**	5/8	PA-66	2000	700/500	23
Glass beads*	60	PP	550	240	10
Mg(OH) ₂ *	60	PP	550	100	10
Mg(OH) ₂	30/60	PP	450	280/130	29
Mg(OH) ₂ *	30/60	PP	700	380/180	29
Mg(OH) ₂	30/40/50	PVC flexible	232	161/161/156	15
Mg(OH) ₂ *	30/40/50	PVC flexible	290	208/214/203	15
Sb ₂ O ₃ *	2.5/5	Polyester	188	124/117	14
Talc	30/60	PP	450	380/310	29
Talc*	30/60	PP	700	480/460	29

*peak value (other values for average rate of heat release)

**fumed silica compounded with PDMS (the values given are peak values from cone calorimeter data)

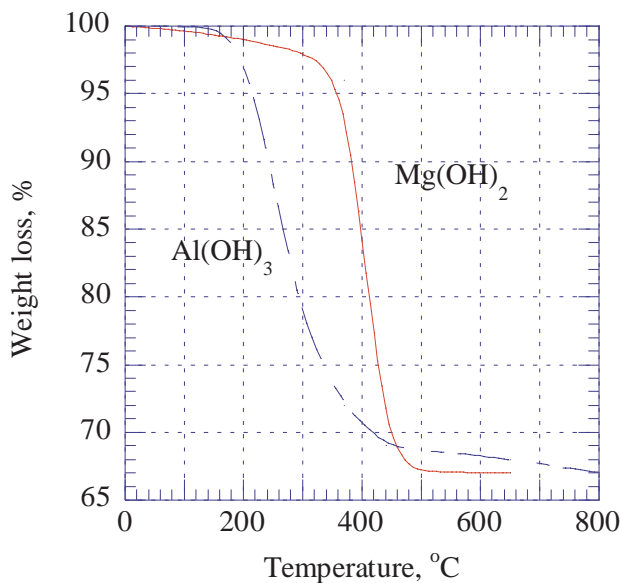


Figure 12.6. Thermogravimetric analysis of $\text{Al}(\text{OH})_3$ and $\text{Mg}(\text{OH})_2$. [Adapted, by permission, from Yeh J T, Yang H M, Huang S S, *Polym. Degradat. Stabil.*, **50**, No.2, 1995, 229-34.]

Flame persistence is reduced to 0 s by the addition of 48 wt% Sb_2O_3 containing decabromodiphenyl oxide.

12.4 HEAT TRANSMISSION RATE

Heat transmission rate, peak of heat transmission rate, propensity of flashover (or fire performance index) are the parameters which characterize heat generation during a fire. These parameters are affected by fillers.^{7,8,10,14,15,23,25,29} Table 12.4 reviews the data from the literature. The addition of certain fillers such as $\text{Al}(\text{OH})_3$, $\text{Mg}(\text{OH})_2$, and Sb_2O_3 substantially reduces the heat transmission rate. Fillers (with the exception of Sb_2O_3) must be used at high concentrations (e.g., 60%) to give the best performance. The modification of fillers by zinc hydroxystannate further reduces the heat transmission rate.¹⁵

The addition of glass fiber, aramid, or graphite has little effect on the peak heat release rates of epoxy and phenolic resins.⁸

12.5 DECOMPOSITION AND COMBUSTION

The decomposition of some fillers and their effect on decomposition and combustion of polymers is discussed below.^{7,8,17,25,29,30,32-36}

Hydroxides of metals, such as aluminum and magnesium and borates containing crystalline water, decompose at specific temperatures and liberate water (Figures 12.6 and 12.7). Magnesium hydroxide is more thermally stable since it begins to decompose at 320°C as compared with 220°C for aluminum hydroxide. The amount of water produced from $\text{Mg}(\text{OH})_2$ is slightly lower than that produced from

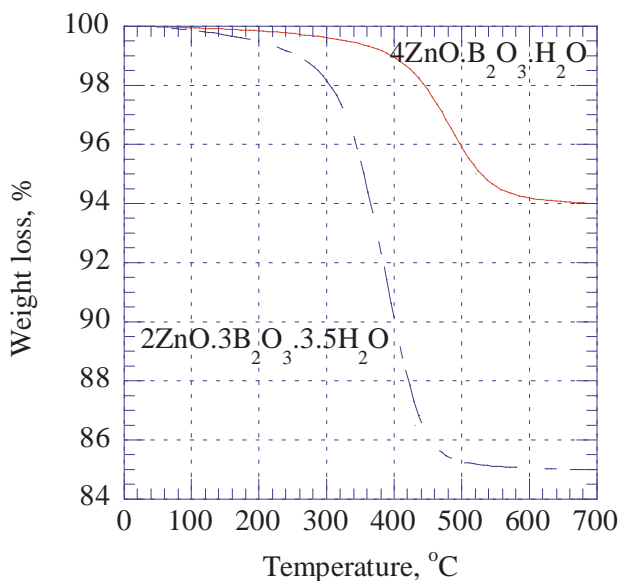


Figure 12.7. Thermogravimetric analysis of zinc borate. [Data from Shen K K, O'Connor R, Addcon '96, Brussels, 1996.]

$\text{Al}(\text{OH})_3$.³⁰ In both cases, the reaction is endothermic which contributes a cooling effect to the degrading polymer. Borates degrade at different temperatures depending on their composition (ammonium - 120°C, barium metaborate - 200°C, zinc borate - 290°C).²¹

Since the decomposition reaction occurs at a specific temperature, the performance of these fillers depends on the properties of the polymers in which they are used. For example, $\text{Mg}(\text{OH})_2$ performs better in polyethylene than $\text{Al}(\text{OH})_3$ because it remains stable during compounding and decomposes at a temperature closer to the decomposition of PE (300–400°C). In unsaturated polyesters, $\text{Al}(\text{OH})_3$ starts to release water at 200°C.¹⁷ The major endothermic peak occurs at 300°C with a heat of decomposition of 300 kJ/mol. About 90% of the water is released between 200 and 400°C. A considerable amount of heat is absorbed before the polymer is affected. The water also dilutes combustible gases and hinders the access of oxygen to the polymer surface. Figure 12.8 shows the difference between talc and a fire retardant filler in PP.²⁹ Talc causes an increase in the combustion rate as its concentration increases, whereas $\text{Mg}(\text{OH})_2$, used at a sufficient concentration (above 20%), decreases the rate of combustion.

It should be noted that the particular grade of filler is important (Figure 12.9). In this study,³⁵ four different grades of $\text{Mg}(\text{OH})_2$ (A to D) were used. These differed in particle size and surface area. Only one filler (A) with the largest particle size (7.7 μm) and the largest surface area (18.9 m^2/g) slowed PP decomposition. $\text{Mg}(\text{OH})_2$ which performs well, has a small, aggregated structure with irregular

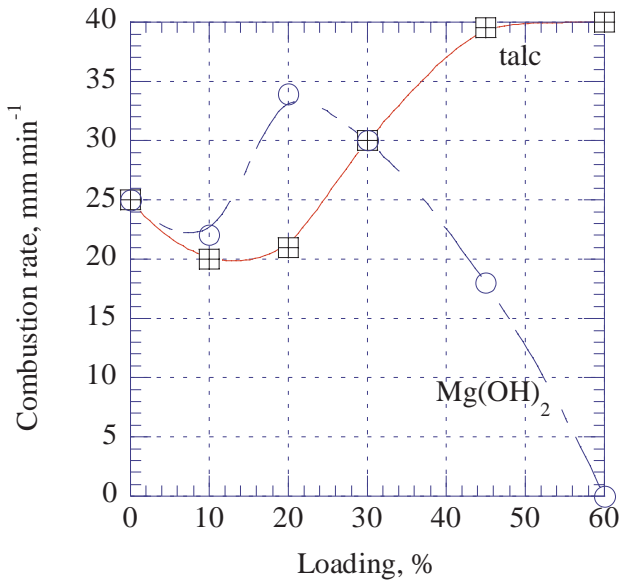


Figure 12.8. Rate of combustion of filled PP. [Data, from Costa L, Camino G, Bertelli G, Borsini G, *Fire & Mat.*, **19**, No.3, 1995, 133-42.]

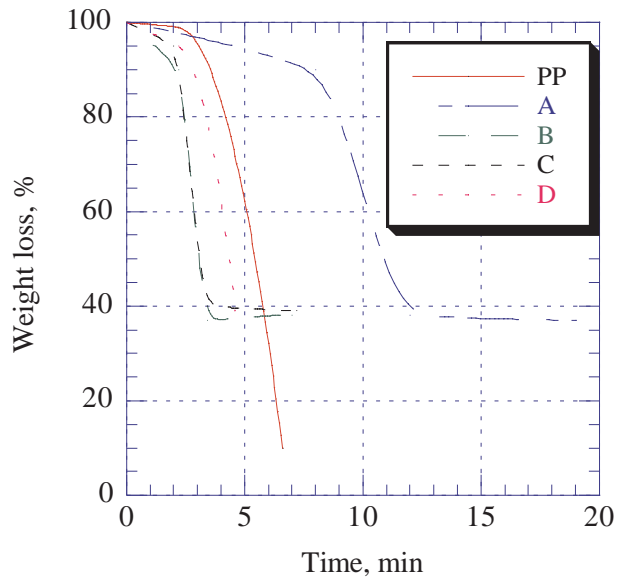


Figure 12.9. Decomposition of Mg(OH)₂ filled PP. [Data from Hornsby P R, Mthupha A, Antec '93. Conference Proceedings, New Orleans, La., 9th-13th May 1993, Vol. II, 1954-6.]

crystallites. Other materials were hexagonal and were composed of much larger crystallites.

Studies of polyamides^{7,25} also illustrate mechanisms involving $\text{Mg}(\text{OH})_2$. $\text{Mg}(\text{OH})_2$ decomposes before the decomposition of PA-6 and after the decomposition of PA-66. The water formed by $\text{Mg}(\text{OH})_2$ before the decomposition of PA-6 gives a fire retardant effect. However, it is possible that the water thus formed may hasten the degradation of the polymer by hydrolyzing it.

Polypropylene was more thermally stable when filled with $\text{Mg}(\text{OH})_2$.³⁵ Calcium carbonate did not stabilize LDPE but the emission of low molecular weight hydrocarbons was reduced due to dilution of the polymer.³³ Calcium carbonate³⁷ stabilizes PVC due to its reaction with HCl. A similar mechanism is found in the stabilization of poly(ethylene acrylate) and ethylene ethyl acrylate copolymer with calcium carbonate where less acids are produced and the interaction with the polymer changes the mechanism of degradation.³³ In this case, the type of calcium carbonate, its coating, and its particle size all have an important impact on performance. Similar behavior was found in the case of $\text{Mg}(\text{OH})_2$ and $\text{Al}(\text{OH})_3$.³⁴ Formation of acetic and propionic acid was decreased during the degradation of ethylene ethyl acrylate copolymer. The endothermic effect was a stabilizing factor if the filler degraded before the polymer. When the degradation temperature of the polymer was higher than the decomposition temperature of the filler, the filler reacted with functional groups in the polymer and affected the mechanism of degradation. Carbon monoxide emission was substantially reduced when zinc borate was used in combination with $\text{Al}(\text{OH})_3$.³⁶

12.6 EMISSION OF GASEOUS COMPONENTS AND HEAVY METALS

There is not much data available on the effect that fillers have on what is emitted during the decomposition of filled products. But some work has been done.^{33-36,38-42}

Decomposition of PA-6 and PA-66 produces NH_3 , H_2O , CO , CO_2 , and hydrocarbons.³⁹ The addition of magnesium hydroxide decreases the amounts of volatiles produced but the chemical components and their proportions are very similar to unfilled polymers. The addition of zeolites to polypropylene changes the mechanism of degradation depending on the zeolite type, its morphology, and dispersion but, in the investigation, the composition of the decomposition products was not determined.⁴¹

The rate of emission of CO and CO_2 from flexible PVC depends on the type of filler added.³⁶ Additions of zinc borate to $\text{Al}(\text{OH})_3$ and $\text{Mg}(\text{OH})_2$ substantially reduced the emission of carbon monoxide. The presence of antimony oxide increased emissions of both CO and CO_2 . The data do not explain why the behavior is different.

The addition of $\text{Al}(\text{OH})_3$, $\text{Mg}(\text{OH})_2$, MgO , and TiO_2 to ethylene ethyl acrylate copolymer did not change the chemical components of the volatiles.³⁴ The only observable difference was related to the concentration of ethylene (higher with $\text{Al}(\text{OH})_3$ than in the presence of the other fillers) and CO_2 (lower with $\text{Al}(\text{OH})_3$ than with $\text{Mg}(\text{OH})_2$ and MgO). There was no detectable difference in the degradation

products from LDPE, poly(ethyl acrylate), and ethylene ethyl acrylate copolymer either unfilled or filled with calcium carbonate.³³

A study of twelve silica fillers in rubber compounds showed that all of the fillers contributed to the formation of nitrosamines. There was a substantial difference in the amounts of nitrosamines detected in the presence of different fillers (from 1.1×10^{-4} to 14.8×10^{-4} mol/kg) but this difference could not be correlated with properties such as their structure or surface area.³⁸

12.7 SMOKE

Fire retardant fillers affect smoke formation.^{6,8,10,14,18,26,29,36,43-46} Table 12.5 gives some data on the specific extinction area. The data show that, with the exceptions of $\text{Al}(\text{OH})_3$ and $\text{Mg}(\text{OH})_2$, fillers have a small effect on smoke suppression.

The effect of fillers on smoke suppression depends on the particle size and crystalline structure of the filler. A new fire retardant, based on a hydrated potassium-magnesium aluminosilicate, in two grades – coarse and fine is available. The fine grade is twice as effective as the coarse grade.^{6,26}

12.8 CHAR

The effect of fillers on char formation was considered in several studies^{14,15,22,35,46} and the data is summarized in Table 12.6.

High efficiency in char formation is one of the reasons for the strong performance of $\text{Mg}(\text{OH})_2$ and $\text{Al}(\text{OH})_3$ as fire retarding additives. This performance can still be enhanced by surface coating the fillers with zinc hydroxystannate. Sb_2O_3 is volatilized from the material and therefore does not affect char formation. Formation of char is an effective method of increasing the fire resistance of materials. The material which forms carbonaceous char has a reduced ability to supply the gaseous fuels required to fuel the fire.

12.9 RECYCLING

Fillers play various roles in the recycling of materials. These include: the use of waste materials as a substitute for fillers (filler replacement), the effect that fillers have on recycling methods and waste production (filler impact on quantity of wastes), recovery of fillers from scrap (filler recovery), and the application of fillers to make materials recyclable (material improvement).⁴⁷⁻⁶⁸ These subjects are discussed below.

A growing volume of waste materials, especially vulcanized rubbers and crosslinked polymers are proving difficult to recycle. As an alternative to their disposal in landfills, there have been many attempts to grind these materials and use the products as a substitute for fillers in composite materials.^{48,49,51,54,59-64} Other non-plastic materials such as glass, paper, natural fibrous materials, and fly ash are also used for filler replacement. There is extensive literature on the use of ground tires as filler replacements.^{59,66} This is a specialized topic with only a minor relationship to fillers.

Table 12.5. Specific extinction area

Filler, wt%		Polymer	Specific extinction area, m ² /kg		Refs.
Type	Concentration		control	with filler	
Al(OH) ₃	30/40/50	PVC flexible	963	622/186/192	15
Al(OH) ₃ + Sb ₂ O ₃	18+9	PVC flexible		678	36
Al(OH) ₃ + ZB	18+9	PVC flexible		928	36
Al(OH) ₃ + Mg(OH) ₂	30+30	PVC flexible		493	36
Glass beads	60	PP	610	600	10
Mg(OH) ₂	30/40/50	PVC flexible	963	398/379/309	15
Mg(OH) ₂	60	PP	610	250	10
Mg(OH) ₂	30/60	PP	600	610/320	29
Sb ₂ O ₃	2.5/5	Polyester	720	663/671	14
Sb ₂ O ₃	10	PVC flexible	777	538	45
Talc	30/60	PP	600	610/530	29
Zinc borate (ZB)	10	PVC flexible	777	719	45

Table 12.6 Char yield

Filler, wt%		Polymer	Char yield, %		Refs.
Type	Concentration		control	with filler	
Al(OH) ₃	20/30/40/50	PVC flexible	3	15/20/30/28	15
Al(OH) ₃	20/50	PVC flexible	3	15/28	14
Mg(OH) ₂	20/30/40/50	PVC flexible	3	25/32/36/38	15
Mg(OH) ₂	20/50	PVC flexible	7	19/35	14
Sb ₂ O ₃	2.5/5	Polyester	20	20/20	14

Polyurethane is a very common crosslinked polymer and many materials produced from it end up as waste. Given the quantity of material, recycling is a major problem. Cryogenic pulverization systems have been developed which can process PU foam to particles smaller than 1 mm (preferably <100 μm).⁶³ These particles are homogenized with polyol and then reacted with isocyanates to produce foam. This foam with 5% pulverized PU foam has a density equivalent to a similar foam produced without the recycled material. A further increase in filler content causes a density increase.⁶³ Pulverized PU foam particles were also tried as a filler in natural rubber vulcanizates with good results.^{60,61} Figure 12.10 shows the effect of PU

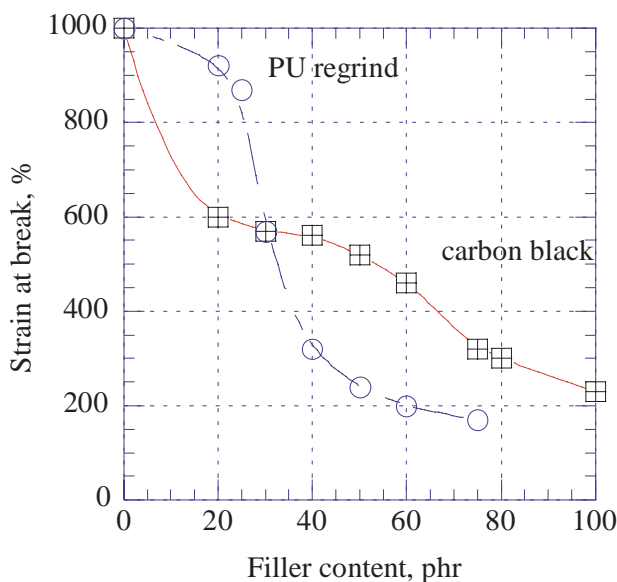


Figure 12.10. Ultimate strain of natural rubber vs. filler content. [Adapted, by permission, from Sombatsomporn N, Sims G L A, *Cell. Polym.*, **15**, No.5, 1996, 317-34.]

regrind on the ultimate strain of vulcanized rubber compared to the effect of carbon black. Lower concentrations of regrind can produce better results than rubber filled with carbon black. The ultimate stress is lower than with carbon black filled vulcanized rubber.

Small quantities of epoxy regrind (5-10%) can be added to epoxy resins without affecting the tensile or flexural strength, tensile or flexural modulus, or dielectric properties.⁵¹ The biggest hurdle in recycling these epoxy materials is the cost of regrinding which at the moment is prohibitive. Molding compounds for automotive applications are used with 15% recycled material.⁴⁸ The regrind replaces the same percentage of calcium carbonate which makes parts up to 7% lighter.

Another area of recycling activity involves the use of alternative materials to replace fillers. Fly ash has been successfully used in polyethylene, providing the composition of fly ash chosen was suitable. Fly ash containing a large amount of CaO was not suitable.⁵⁴ The use of natural or recovered fibers (wood pulp, paper, plant fibers, etc.) is a growing market due to their low cost, biodegradability, and natural occurrence in renewable resources. Treated flax fiber in PP gives a reinforcement comparable to E-glass.⁶² In a more unusual application, material recovered from ground glass bottles was used in polyurethane and acrylic paints. In acrylic paints, this filler had good flattening characteristics.⁶⁴ Plastics recovered from municipal wastes perform better as a filler when cellulose recovered from paper is added to them.⁶⁶

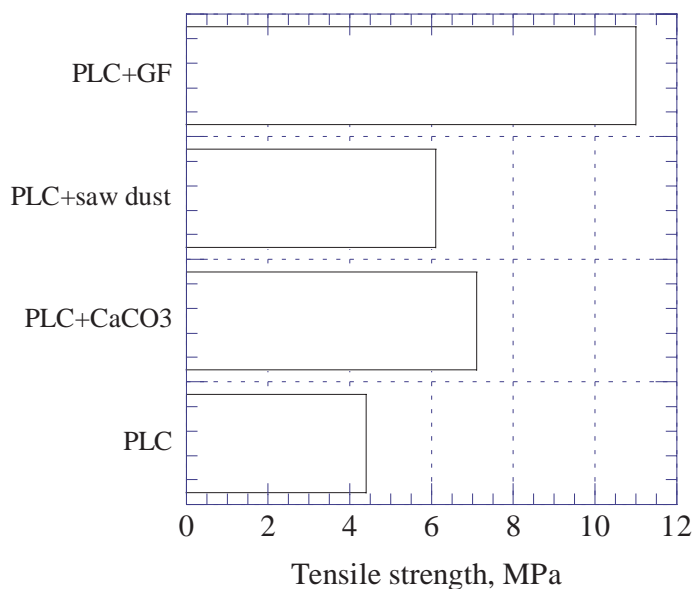


Figure 12.11. Tensile strength of post-consumer plastic containers reprocessed with different fillers. [Adapted, by permission, from La Mantia F P, **Recycling of PVC & Mixed Plastic Waste**, ChemTec Publishing, Toronto, 1996.]

Fillers have a noticeable impact on waste reprocessing methods. Expired products contain a large proportion of fillers which must be dealt with.⁶⁵ A plant in Bernau, Germany processes circuit boards using incineration. The material contains 49% glass wool which remains after incineration.⁶⁷ Solid wastes from electronic scrap contain 19% glass fiber. To date, no use has been found for this material. Trials are under way to remelt it into glass. Composting of materials containing fillers is difficult because the filler causes them to degrade more slowly. An addition of a small amount of calcium carbonate (7%) to starch slows down its composting process rate by half.⁶⁷

Filler recovery from expired materials is still in its infancy. Glass fibers from recycled sheet-molding compounds processed by chemical means have the potential to replace up to half of the glass fibers used in bulk-molding compounds.⁴⁹ Clay is used as a decolorant in the lubricating oil industry. This clay can be reused with good results without any prior treatment as a neutral filler in vulcanized rubber.⁵⁶ Paper recycling requires that calcium carbonate and kaolin be removed prior to recycling. Removal by flotation was studied.⁵³

Fillers have the potential to be used to improve recycled materials.⁵² Two major problems in plastic recycling can potentially be addressed by fillers. Recycled plastics are frequently processed as a mixture of different polymers with various concentrations of each. This is especially true in the case of municipal wastes. There is a problem of compatibility between polymer components of these wastes

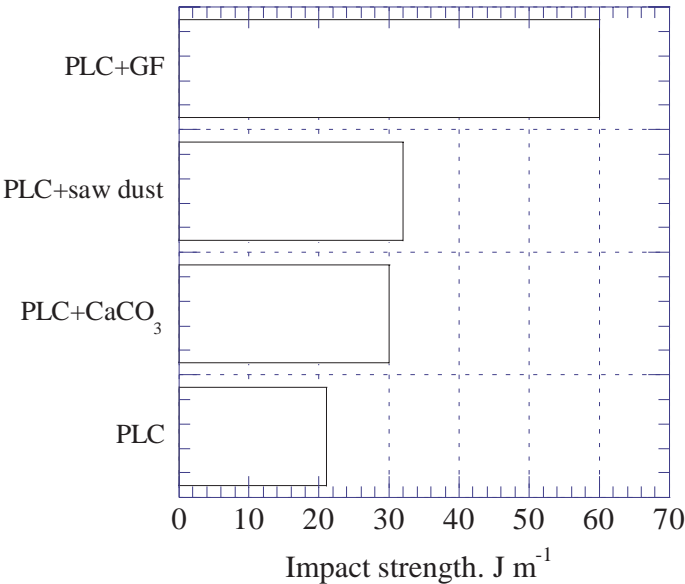


Figure 12.12. Impact strength of post-consumer plastic containers reprocessed with different fillers. [Adapted, by permission, from La Mantia F P, **Recycling of PVC & Mixed Plastic Waste**, ChemTec Publishing, Toronto, 1996.]

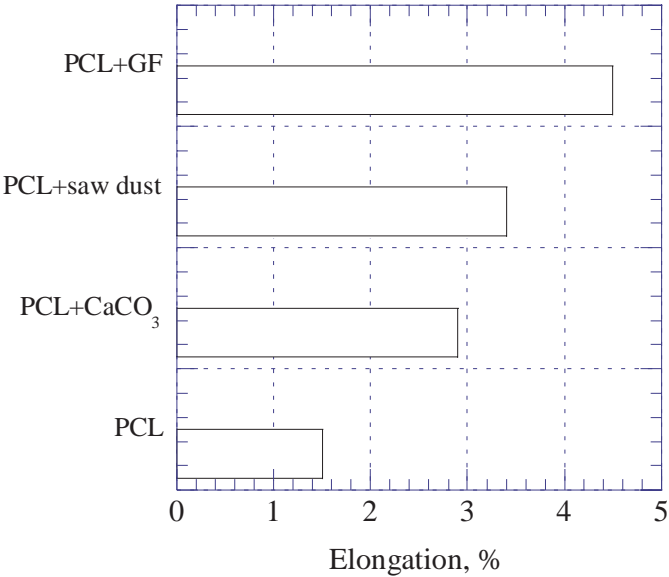


Figure 12.13. Elongation of post-consumer plastic containers reprocessed with different fillers. [Adapted, by permission, from La Mantia F P, **Recycling of PVC & Mixed Plastic Waste**, ChemTec Publishing, Toronto, 1996.]

which results in products having inferior mechanical characteristics. The mechanical characteristics of mixed plastic blends can be improved by the addition of cal-

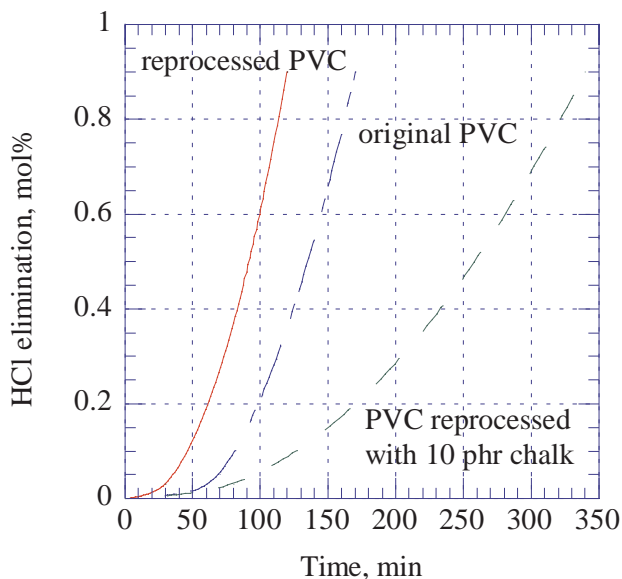


Figure 12.14. Dehydrochlorination rate of PVC. [Adapted, by permission, from Braun D, Kraemer K, *Recycling of PVC & Mixed Plastic Waste*, La Mantia F P, Ed. *ChemTec Publishing*, Toronto, 1996.]

cium carbonate, talc, or glass fibers.⁶⁶ A recycled PE/PS blend was considerably improved by the addition of treated wood fiber.⁵⁷ Figures 12.11 to 12.13 show the improvement of properties in post-consumer plastic containers by adding various fillers. Tensile and impact strength and elongation were improved.⁶⁸

Figure 12.14 shows the effect of calcium carbonate on PVC reprocessing.⁶⁸ An addition of 10% chalk improves the thermal stability of the material to the extent that it performs better than the material before reprocessing.

REFERENCES

- 1 Le Bras M, Bourbigot, Le Tallec Y, Laureyns J., *Polym. Degradat. Stabil.*, **56**, 1997, 11-21.
- 2 Nagieb Z A, El-Sakr N S, *Polym. Degradat. Stabil.*, **57**, 1997, 205-9.
- 3 Benrashid R, Nelson G L, *J. Fire Sci.*, **11**, No.5, 1993, 371-93.
- 4 Krisher J A, Marshall S S, Antec '97. Conference proceedings, Toronto, April 1997, 2928-30.
- 5 Nichols K, Solc J, Shieu F, Antec '93. Conference Proceedings, New Orleans, La., 9th-13th May 1993, Vol. II, 1938-42.
- 6 Schott N R, Rahman M, Perez M A, Antec '94. Conference Proceedings, San Francisco, Ca., 1st-5th May 1994, Vol. III, 2846-50.
- 7 Hornsby P R, Wang J, Jackson G, Rothon R N, Wilkinson G, Cosstick K, Antec '94. Conference Proceedings, San Francisco, Ca., 1st-5th May 1994, Vol. III, 2834-9.
- 8 Hshieh F Y, Beson H D, *Fire Mater.*, **21**, 1997, 41-9.
- 9 Toure B, Lopez Cuesta J-M, Longerey M, Crespy A, *Polym. Degradat. Stabil.*, **54**, Nos 2-3, 1996, 345-52.
- 10 Rothon R N; Hornsby P R, *Polym. Degradat. Stabil.*, **54**, Nos 2-3, 1996, 383-5.
- 11 Toure B, Lopez Cuesta J M, Gaudon P, Benhassaine A, Crespy A, *Polym. Degradat. Stabil.*, **53**, No.3, 1996, 371-9.
- 12 Kretzschmar B, *Kunststoffe Plast Europe*, **86**, No.4, 1996, 20-2.

- 13 Toure B, Lopez-Cuesta J, Benhassaine A, Crespy A, *Int. J. Polym. Analysis and Characterization*, **2**, No.3, 1996, 193-202.
- 14 Cusack P, Flame Retardants '96. Conference proceedings, London, 17th-18th Jan.1996, 57-69.
- 15 Baggaley R G, Hornsby P R, Yahya R, Cussak P A, Monk A W, *Fire Mater.*, **21**, 1997, 179-85.
- 16 Elfving K, Soderberg B, *Reinf. Plast.*, **40**, No.6, 1996, 64-5.
- 17 Brown N, Linnert E, *Reinf. Plast.*, **39**, No.11, 1995, 34-7.
- 18 Maxwell J, **Plastics in High Temperature Applications**, Pergamon Press, Oxford, 1992.
- 19 Smith R, Enhancing Polymers Using Additives and Modifiers II, Shawbury, 1996.
- 20 Martin P A, Buszad D L, Papez M, Addcon '96, Brussels, 1996.
- 21 Shen K K, O'Connor R, Addcon '96, Brussels, 1996.
- 22 Levchik G F, Levchik S V, Lesnikovich A I, *Polym. Degradat. Stabil.*, **54**, Nos 2-3, 1996, 361-3.
- 23 Pape P G, Romenesco D J, Antec '97. Conference proceedings, Toronto, April 1997, 2941-52.
- 24 Clemens M L, Doyle M D, Lees G C, Briggs C C, Day R C, Flame Retardants '94. Conference proceedings, London, 27th-28th January 1994, 193-202.
- 25 Hornsby P R, Wang J, Cossick K, Rothern R, Jackson G, Wilkinson G, Flame Retardants '94. Conference proceedings, London, 27th-28th January 1994, 93-108.
- 26 Schott N R, Rahman M, Perez M A, *J. Vinyl and Additive Technol.*, **1**, No.1, 1995, 36-40.
- 27 Rothern R N, *Macromol. Symp.*, **108**, 1996, 221-9.
- 28 Le Bras M, Bourbigot S, *Fire & Mat.*, **20**, No.1, 1996, 39-49.
- 29 Costa L, Camino G, Bertelli G, Borsini G, *Fire & Mat.*, **19**, No.3, 1995, 133-42.
- 30 Yeh J T, Yang H M, Huang S S, *Polym. Degradat. Stabil.*, **50**, No.2, 1995, 229-34.
- 31 Fu-Yu Hsieh, Bryan C J, Pedley M D, *Fire & Mat.*, **18**, No.6, 1994, 389-91.
- 32 Innes J D, Addcon '96, Brussels, 1996.
- 33 McNeill I C, Mohammed M H, *Polym. Degradat. Stabil.*, **49**, No.2, 1995, 263-73.
- 34 McNeill I C, Mohammed M H, *Polym. Degradat. Stabil.*, **48**, No.1, 1995, 189-95.
- 35 Hornsby P R, Mthupha A, Antec '93. Conference Proceedings, New Orleans, La., 9th-13th May 1993, Vol. II, 1954-6.
- 36 Fern D J, Shen K K, Antec '94. Conference Proceedings, San Francisco, Ca., 1st-5th May 1994, Vol.III, 3522-6.
- 37 Braun D, Kraemer K, **Recycling of PVC & Mixed Plastics**, Editor La Mantia F P, *ChemTec Publishing*, Toronto, 1996.
- 38 Gorl U, De Kok J J, Bomal Y, Cochet P, Mueller H, *Kaut. u. Gummi Kunst.*, **47**, No.6, June 1994, 430-4.
- 39 Hornsby P R, Wang J, Rothern R, Jackson G, Wilkinson G, Cossick K, *Polym. Degradat. Stabil.*, **51**, No.3, 1996, 235-49.
- 40 Ketrup A A, Lenoir D, Thumm W, Kampke-Thiel K, Beck B, *Polym. Degradat. Stabil.*, **54**, Nos 2-3, 1996, 175-80.
- 41 Zhao W, Hasegawa S, Fujita J, Yoshii F, Sasaki T, Makuuchi K, Sun J, Nishimoto S, *Polym. Degradat. Stabil.*, **53**, No.2, 1996, 199-206.
- 42 *Reinf. Plast.*, **40**, No.10, 1996, 66-70.
- 43 Modesti M, Simioni F, Albertin P, *Cell. Polym.*, **13**, No.2, 1994, 113-24.
- 44 Molesky F, Schultz R, Midgett S, Green D, *J. Vinyl Additive Technol.*, **1**, No.3, 1995, 159-61.
- 45 Herbert M J, Flame Retardants '96. Conference proceedings, London, 17th-18th Jan.1996, 157-72.
- 46 Miller B, *Plast. World*, **54**, No.12, 1996, 44-9.
- 47 Smock D, *Plast. World*, **54**, No.12, 1996, 35
- 48 *Reinf. Plast.*, **39**, No.4, 1995, 8-9.
- 49 Winter H, Mostert H A M, Smeets P J H M, Paas G, *J. Appl. Polym. Sci.*, **57**, No.11, 1995, 1409-17.
- 50 Mayadunne A, Bhattacharya S N, Kosior E, Boontanjai C, Antec 95. Volume I. Conference proceedings, Boston, Ma., 7th-11th May 1995, 1178-82.
- 51 Whalen J P, Poston D D, Antec '94. Conference Proceedings, San Francisco, Ca., 1st-5th May 1994, Vol. I, 924-8.
- 52 Jacobson K E, Eller R, Polyolefins VIII. Conference Proceedings, Houston,Tx., 21st-24th Feb.1993, 494-509.
- 53 Liphard M, Von Rybinski W, Schreck B, *Prog. Coll. & Polym. Sci.*, **95**, 1994, 168-74.
- 54 Alkan C, Arslan M, Cici M, Kaya M, Aksoy M, *Resources Conserv. & Recycling*, **13**, Nos.3-4, 1995, 147-54.
- 55 Long Y, Tiganis B E, Shanks R A, *J. Appl. Polym. Sci.*, **58**, No.3, 1995, 527-35.
- 56 Chen X, Zhang S, Wang X, Yao X, Chen J, Zhou C, *J. Appl. Polym. Sci.*, **58**, No.8, 1995, 1401-5.

- 57 Simonsen J, Rials T G, *J. Thermoplast. Composite Mat.*, **9**, No.3, 1996, 292-302.
- 58 Graham J, Hendra P J, Mucci P, *Plast. Rubb. Comp. Process. Appln.*, **24**, No.2, 1995, 55-67.
- 59 Dierkes W, *J. Elastomers Plast.*, **28**, No.3, 1996, 257--78.
- 60 Sombatsompop N, Sims G L A, *Cell. Polym.*, **15**, No.5, 1996, 317-34.
- 61 Sims G L A, Sombatsompop N, *Cell. Polym.*, **15**, No.2, 1996, 90-104.
- 62 Burger H, Koine A, Maron R, Mieck K P, *Int. Polym. Sci. Technol.*, **22**, No.8, 1995, T/25-34.
- 63 Sims G L A, Angus M W, Crosley I, Antec '95. Vol. II. Conference Proceedings, Boston, Ma., 7th-11th May 1995, 2166-70.
- 64 Athey R D, Kirkland T, Lindblom G, Swoboda J, *Eur. Coatings J.*, No.11, 1995, 793-8.
- 65 Hohenberger W, *Kunststoffe Plast Europe*, **86**, 7, 1996, 18-20.
- 66 La Mantia F P, **Recycling of Plastic Materials**, *ChemTec Publishing*, Toronto, 1993.
- 67 Krause H H, Penninger J M L, **Conversion of Polymer Wastes & Energetics**, *ChemTec Publishing*, Toronto, 1994.
- 68 La Mantia F P, **Recycling of PVC & Mixed Plastic Waste**, *ChemTec Publishing*, Toronto, 1996.