multiscrew extrusion. If a single-screw extruder is used, the stabilizer level should be raised from that shown below to the range of 0.8–1.5 phr, and 2–2.5 phr of a processing aid added.

PRESSURE PIPE

PVC (K-65)	100
$CaCO_3$ (0.8 μm)	2–4
TiO_2 (rutile)	1–2
$CaSt_2$	0.4–0.8
Paraffin wax (165 °F mp)	0.8–1.0
Oxidized PE wax	0.1–0.2
Stabilizer	0.4

Recommended stabilizers include Thermolite® (Atofina) 140 and 176; Mark® (Chemtura) 1939 and 1996. Advastab® (Rohm & Haas) TM-694 and 697; Interstab® (Akcros) T-5277 and Reatinor® RT-6611 and 6612 (Reagens). Some of the reverse ester stabilizers for pipe applications have boosted tin levels and may be used (in favorable circumstances) at 0.3 or 0.35 phr instead of 0.4. In the above recipe, $CaCO_3$ and TiO_2 provide the necessary opacity, the latter adding UV light resistance. The levels are held low to maximize burst resistance and impact strength. The remaining ingredients comprise the lubricant package. The level of $CaSt_2$ is adjusted to provide the optimum fusion speed during extrusion and to provide internal lubrication; the level of paraffin wax is adjusted to provide external lubrication. For convenience in adding to the mixer, flaked paraffin wax, such as MarkPet® (Chemtura) or Sunolite® 160 (Sun Oil) may be replaced by refined paraffin oil, such as MarkLube® PW-10. The use of low levels of oxidized PE wax improves printability and tends to add combination action to the lubricant system.

In some parts of the world, the above formulation would be run with a stabilizer composed of 0.5–1.0 phr of stearate-coated tribasic lead sulfate and 0.2–0.3 phr dibasic lead stearate, typically with 1–2 phr of an ester lubricant and reduced paraffin wax. For a gray product, a blend of TiO_2 and fine-particle carbon black would be used to provide UV light protection. Although such pipe has been in service for many years without confirmed ill effects, the use of lead stabilizers cannot be recommended, since it is unnecessary, of no significant cost advantage, and detracts from popular acceptance. If (actually when) it becomes necessary to convert from use of lead stabilizers in rigid PVC, it is simpler to convert to a calcium/zinc system than to organotin. The lubrication values of lead and Ca/Zn stabilized compounds are similar and neither requires protecting steel surfaces from sulfur corrosion from tin mercaptides. In addition, there is no concern with lead–sulfur staining. Materials cost will increase from the cost and the much increased stabilizer level needed (3–4 hr), and output may also suffer. An intermediate step is to convert pressure pipe only, as is being done in parts of Europe, with a lead one pack being replaced by a Ca/Zn one pack, such as Reapak® B-TU/1020 and 1062 (Reagens) or Naftomix® 1520 and 1524 (Chemson).

In North America, CPVC pipe uses stabilizers high in tin content, such as Akcrostab® T-4905, Mark® 1900, Advastab® TM-161, Thermolite® T-31, or functional equivalents. Lead stabilizers are used elsewhere.

PVC pipe used for low-pressure applications for drain, waste and vent purposes (DWV) is more highly extended, but similar:

DWV PIPE

PVC (K-65)	100
Impact modifier	2–3
$CaCO_3$ (0.8–1.0 μm)	10–40
TiO_2	0.5–1.0
$CaSt_2$	0.6–0.8
Paraffin wax (165 °F mp)	1.2–1.5
Oxidized PE wax	0.1–0.2
Stabilizer	0.3–0.5

The most common practice is to use the same stabilizer throughout the plant. (Note that any blending of different tin stabilizers, even those thought equivalent, should be done only after thorough small-scale evaluation so as to preclude unexpected effects from minor additives.) With the higher filler loading used in this application, it is necessary to add an impact modifier. The same is true with electrical conduit, where the above recipe also applies, except that TiO_2 is often reduced or eliminated, or blended with carbon black to generate a gray product. Processing aids are sometimes added with DWV and conduit extrusions, particularly if single-screw extruders are used. In the latter case, stabilizers are used at a 0.8–1.5 phr level. In areas where lead stabilizers have been used, conversion has begun with Ca/Zn one packs, such as Reapak® G-Tu/1059 or Naftomix® 2300, at 2–3 phr.

Except in cases where the outer layer is acrylic, for example, Acryligard® (Rohm & Haas) or PVDF (Kynar®), vinyl siding is extruded in dual layers, mainly an inner layer, "substrate," and the outer weatherable layer, "capstock." (The terms come from siding jargon that predates the appearance of PVC.) The bulk of the product is, of course, substrate, which uses reverse ester tin stabilizers:

SIDING SUBSTRATE

PVC (K-65)	100
Impact modifier	3–5
$CaCO_3$	7–15
TiO_2	0–1
$CaSt_2$	1–1.2
165 wax	1–1.3
Oxidized PE wax	0.1–0.2
Stabilizer	0.8–1.2

Recommended reverse ester tin stabilizers include Thermolite® 140, 172 butyltins and 174 methyltin; Mark® 1367 butyltin and 1939, 1971, 2903 methyltins; Advastab® TM-286SP; and Interstab® T-5201 and 5286. Substrate recipes may also include 0.15–0.25 phr of a lubricating processing aid. Addition of zeolite or hydrotalcite at a level of 0.5–1.0 phr will enable use of the low end of the above recommended usage and will provide for gradual rather than abrupt failure in case of factory misadventure. A suitable costabilizer for this purpose is Halstab® 1214 coated zeolite.

Even though filler extension is low, impact modifiers are required because of processing: extrusion of a flat sheet, embossing of a pattern simulating wood, and thermoforming to the complex shape of the siding, as well as for protection from impact during installation and in service. Vinyl siding has as yet made only slight penetration of the European market. It is anticipated that products will use the Ca/Zn one packs that are replacing lead stabilizers in window profile.

Capstock stabilizers tend to be based on tin IOTG. A typical recipe comprises the following:

SIDING CAPSTOCK

PVC (K-65 to 68)	100
Impact modifier	4–6
TiO_2	8–10
$CaSt_2$	1–1.5
165 wax	1–1.5
Processing aid	0.2–1.0
Tin IOTG stabilizer	0.8–1.2

Recommended stabilizers include Thermolite® 161, 172, 174, 340, and 380; Mark® 1367, 1900, and 2284A; Advastab® TM-181 and TM-186; Interstab® T-5003 and 5262; Reatinor® 414 (Reagens); PlastiStab® 2820 (Halstab); Baerostab® M 25S (Baerlocher); and Therm-Chek® 840 (Ferro). There is also now some use of reverse ester tins with relatively high tin levels, such as Mark® 1971, Advastab® TM-182 and TM-697, and Interstab® T-5278, recommended at 1.4–1.75 phr. Improved UV light resistance can be gained by use instead of a combination mercaptide/carboxylate stabilizer such as Mark® T-634, or 2270F, recommended at 2–3 phr, or of a high efficiency tin carboxylate, such as PlastiStab® 2808 (Halstab), Therm-Chek® 835, Reatinor® 460, or Interstab® T-876 and T-878. These options should be considered for siding applications in Southern locations, as well as the use of acrylic topcoats. Improved UV light resistance with tin mercaptide stabilizers also results from addition of about 1.0 phr of a costabilizer such as Halstab® 1214 and reduction of stabilizer level. Ca/Zn stabilizers that might be considered include Baerostab® B 634 and MC 9041 FP/1 and ThermChek® RC 437P.

Impact modifiers are again used despite the low filler loading because of processing and service requirements. In nonwhite versions, pigment is used in both layers, not merely to permit a description of being uniformly colored, but because the capstock would be hard pressed to carry sufficient pigment. In some cases, sufficient titanium dioxide is added to the substrate in white siding as to make it difficult to distinguish the components visually.

Window and picture frame profile extrusions use compounds similar to siding capstock recipes but typically are based on slightly higher molecular-weight resin, compensating for an increased additive package designed for maximum extrusion line speed.

PROFILE EXTRUSION

PVC (K-67)	100
Impact modifier	5–6
Processing aid	0.7–1.0
Lubricating processing aid	0–0.2
$CaCO_3$ (0.8 μm)	0–5
TiO_2 (or blend with pigment)	8–10
$CaSt_2$	0.8–1.2
165 wax	0.8–1.2
Stabilizer	1–1.5

Recommended stabilizers include Thermolite® 161 and 380; Mark® T-634, 2284A, 1900 and 1996; Advastab® TM-181 and TM-186; Akcrostab® T-5003 and T-7020; Reatinor® 403 and 404; and Therm-Chek® 840. Again, it may be advantageous to add 1 phr of a zeolite acid absorber, such as Halstab® 1214 while reducing the stabilizer to 1 phr. In Europe, lead and lead/cadmium one packs have started to be replaced by Ca/Zn stabilizers, such as Naftomix® 6300 and 6500, or Baerostab® B 634 and MC 9041 FP/1, at 2–3 phr.

Food-grade blow-molded bottles use ingredients FDA sanctioned per 21CFR 178.2650 at permitted levels, with low-odor octyl or methyltins:

FOOD GRADE BOTTLE

PVC (K-57)	100
MBS impact modifier	12–15
Processing aid	1.5–2.0
Lubricating processing aid	0.5–1.0
Internal lubricant	1.5–2.0
External lubricant	0.1–0.2
Stabilizer	1.5–2.0

Recommended stabilizers include Thermolite® methyltin 190, and octyltins 890 and 890S; Mark® OTM octyltin or methyltin 1995; Akcrostab® methyltin T-7021 and octyltin T-883; Reatinor® octyltins 804 and 807; and PlastiStab® 2807. Up to

2.0 percent by weight of stabilizer may be used per the above FDA sanction. Food-grade rigid PVC sheet uses the same stabilizers and is similar:

FOOD GRADE SHEET

PVC (K-60)	100
Impact modifier	6–12
Processing aid	1.5–2.0
Lubricating processing aid	0.7–1.0
Internal lubricant	1.2–1.5
Stabilizer	1.2–1.5

In both cases, toners may be added to provide a bluish tint. General purpose (non-food-grade) clear sheet traditionally used 2.0–2.5 phr of a carboxylate stabilizer, such as PlastiStab® 2808, Therm-Chek® 835, Reatinor® 460 or 480, or Interstab® T-876 or T-878; or a carboxylate/mercaptide, such as Mark® T-634 or 2270F, or Akcrostab® T-5507A. With the advent of low-odor tin mercaptides, much of this has been converted from the more expensive carboxylates. For clear extruded sheet, the following is typical:

CLEAR EXTRUDED SHEET

PVC (K-60)	100
Impact modifier	5–10
Processing aid	1–2
Lubricating processing aid	0.4–1.0
Oxidized PE wax	0–0.2
Internal lubricant	0.5–1.0
Stabilizer	0.8–1.7

Suitable stabilizers include Thermolite® 108, Mark® 2270F, Akcrostab® T-5063, Advastab® TM-181 and TM-186, and functional equivalents as described above. Clear calendered sheet is similar, except for higher levels of internal lubricant (1.2–1.5 phr), processing aid (1.5–2.0 phr), lubricating processing aid (0.7–1.0 phr), and usually the addition of 0.1–0.5 phr of an external lubricant. In Europe, Ca/Zn one packs, such as Naftomix® 7205, are also used at 2–3 phr. Corrugated clear roofing has tended to retain the use of carboxylate stabilizers, and generally includes a UV light absorber and high levels of acrylic impact modifier:

CORRUGATED CLEAR ROOFING

PVC (K-58 to 60)	100
Impact modifier	6–15
Processing aid	0.5–1.0

Lubricating processing aid	1.0–1.5
Internal lubricant	0.8–1.0
External lubricant	0.2–0.3
UV light absorber	0.3
Stabilizer	2–3

Clear rigid profiles for outdoor use are very similar. For general purpose rather than outdoor use, pigmented opaque sheet is similar except that low-odor tin IOTG stabilizers are used. The levels of impact modifier, processing aids, and lubricants vary with the extent of filler and pigment usage.

The most common injection-molded items made from rigid PVC are pipe fittings. Butyltin and methyltin IOTG stabilizers are used.

PIPE FITTINGS

PVC (K-55 to 58)	100
Impact modifier	0–5
Processing aid	0–1.5
Lubricating processing aid	0–0.5
$CaSt_2$	1–1.5
165 wax	1–1.5
TiO_2	1–3
Stabilizer	1.5–2.0

Stabilizers specifically recommended include Thermolite® 31S, 108, and 161; Mark® 1900; Advastab® TM-181 and TM-2831M, Akcrostab® T-7020; and others noted above for use in profile or capstock formulations. Impact modifier level will increase as the size of the fitting becomes greater. Weatherable fittings, such as for pipe used outside in decorative or garden applications, have low levels of calcium carbonate added, requiring use of an impact modifier, typically 2–3 phr.

Injection-molded electrical boxes use blends of titanium dioxide and carbon black for exterior (gray) products. Interior electrical boxes are often colored blue. All are deep-draw complex moldings, requiring processing aids and lubricants at the upper end of the above range. In addition, impact modifiers are used at a 2–5 phr level. Use of a large additive package to facilitate injection molding can sometimes prejudice heat distortion under load characteristics. An approach that provides some compensation for this is the use of solid tin stabilizers. A particularly effective choice is dibutyltin mercaptopropionate (Mark® 2255, Akcrostab® T-186), used at a 1–2 phr level. Alternatively, it can be used at 1 phr with 1 phr of a treated zeolite booster, such as Halstab® 1214. In Europe, Ca/Zn one packs, such as Naftomix® 1911, are also used, at about 3 phr.

Tin powders also find use in injection-molded CPVC, such as for electrical boxes, to maximize resistance to heat distortion. Other tin stabilizers used in molded CPVC include Thermolite® 30S, Advastab® TM-161, Mark® 1900, and Akcrostab®

T-4905. An interesting CPVC costabilizer is the Ferro UV light Na/Ba/organophosphate stabilizer UV-Chek® AM-595.

One of the most rapidly expanding areas of PVC technology is that of rigid foam products, leading to "foam core" pipe, siding substrate, sheet, profile, and wood composites (plastic lumber). Comparisons between formulations for solid and foamed products are illustrative:[20]

DWV PIPE AND FOAM CORE AND SKIN

	DWV Pipe	Foam Core and Skin	
PVC (K-65)	100	100	100
Impact modifier	2	—	—
Processing aid	—	2–4	0.2–1.0
$CaSt_2$	0.6–0.8	0.6–0.8	0.6–0.8
165 wax	1.2–1.5	0.8–1.0	1.0–1.2
Oxidized PE wax	0.1–0.2	—	—
$CaCO_3$	10–30	5–10	3–5
TiO_2	0.5–1.0	0.5–1.5	1.0–1.5
Stabilizer	0.3–0.5	0.4–0.6	0.3–0.4
Blowing agent	—	0.3–0.5	—

What does not appear in the formulation is the effect of foaming, a decrease in overall density of almost a factor of three. In comparison, the increase in additive usage is trivial in cost. Although requiring special purpose extrusion equipment and careful control, foam core pipe is much more convenient to install in the field than solid pipe and has gained acceptance in larger sizes. In the United States, the blowing agent is typically azodicarbonamide, which is activated in a useful temperature range by calcium stearate. Foam core pipe is also gaining acceptance in Europe, using either lead or Ca/Zn one packs, such as Naftomix® 1805 and Baerostab® B 1035. The comparison of solid and foam extruded sheet is similarly instructive:

SOLID AND FOAM SHEET

	Solid Sheet	Foam Sheet
PVC (100 phr)	K-67	K-60
Impact modifier	5–10	2–4
Processing aid	1.5–2.0	4–6
Lubricating processing aid	0.1–0.4	—
$CaSt_2$	0.6–1.0	0.3–0.5
165 wax	—	0.6–1.0
$CaCO_3$	0–5	7–10
TiO_2	0–1	1–3
Stabilizer	0.8–1.7	0.7–0.8
Blowing agent	—	0.3–0.5

The resultant products are very useful. The effects of foam density on properties have been reported by Patterson.[21] Thermal conductivity is reduced greatly, stiffness is increased, and the product can be cut, sawed, or nailed much like another cellular polymer, wood. The logical conclusion is to combine the cellulosic compound, wood, with PVC to generate plastic lumber. Typically azodicarbonamide (and often foam structure control agents) are added, but Matuana has reported that, without drying, moisture in the wood fiber can be used as the blowing agent.[22] Typically, however, the wood fiber is dried thoroughly and often coated so as to generate a hydrophobic surface. At first, coatings of $CaSt_2$ and ethylene bis-stearamide (EBS) were used. More recently, proprietary coatings such as Glycolube® WP-2000 (Lonza), Mark® W15, TPW® 012 and 251 (Struktol), and Safoam® WSD and WLB (Reedy) have been used. At this point, a scavenging agent may be added to the wood fiber to sequester tannins, which are generated by various trees as parasite controls. These are phenolic compounds that are powerful chromophores; their solubility in water leads to migration to the surface, where a variety of light-colored articles in contact with the PVC/wood composite may be noticeably stained. One that has been reported is Carboquat® (Lonza).

PVC WOOD COMPOSITE

PVC (K-65)	100
Wood fiber	10–80 but typically 50–60
Processing aid	2–6
Lubricating processing aid	0–1
$CaSt_2$	0.6–1.2
165 wax	1–1.2
Oxidized PE wax	0–0.2
Stabilizer	1–2
Azodicarbonamide	0.4–0.6

Despite encapsulation by PVC, compounds such as the above should contain a biocide if used as plastic lumber outdoors. Those reported effective include thiazolyl benzimidazole (Irgaguard® F3000; Ciba), dichlorooctylisothiazolone (Vinyzene® SB27 (Rohm & Haas) and Micro-Chek® 11 (Ferro), and zinc borate (Borogard® ZB; US Borax). Wood fiber composites are discussed in greater detail in Chapter 17.

4.2.4 Tin Stabilizers in Flexible PVC Compounds

The major use of tin stabilizers in flexible PVC is in flooring topcoats and foamed plastisols produced in Europe. Carboxylates such as those described above for best weatherability in profile and siding capstocks are used at 1–2 phr. There is no question that this approach provides exceptionally good color retention during processing and service. Cost considerations work against analogous use in North America, where such applications are served by Ba/Zn, Ca/Zn and Zn-based stabilizers that are actually mainly epoxidized oil and phosphites. Flooring applications where unusually