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PROPERTIES AND PERFORMANCE OF BLENDS OF PVC WITH NEW, HIGH-IMPACT THERMOPLASTIC RESINS

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Abstract - Heat build-up in dark colored rigid PVC construction items, such as siding, results in poor exterior durability. Dimensional stability and color retention are unacceptable. These properties can be greatly improved by blending PVC with modified styrene/acrylonitrile copolymers. Initial dark-color formulations have heat distortion temperatures 20^{o}F higher than that of PVC. Natural and accelerated weathering have demonstrated color and gloss retention much superior to those of comparable PVC colors.

INTRODUCTION

The market growth of rigid PVC profile extrusions in construction applications, such as siding, has been restricted because of the inability to provide dark colors with good exterior durability. Dimensional stability and color retention have both been unacceptable. This paper deals with one method of achieving exterior durability by blending PVC with new, proprietary, high-impact thermoplastic resins.

Articles exposed to sunlight can attain temperatures which are much higher than ambient. This effect is, of course, most pronounced where the radiant energy is very high and where the article has a high heat absorptivity. In many parts of the world during the summer, dark colored objects can attain temperatures as high as 175^{o}F (80^{o}C). Many rigid PVC items used in outdoor construction, such as siding, siding accessories, window frames, etc., are exposed to such radiation and can attain these temperatures if they are sufficiently dark to have high absorption for radiant energy. Several undesirable effects can take place as PVC is heated to such extreme temperatures. If the heating is non-uniform, thermal expansion will also be non-uniform and temporary distortion can take place. If there are stresses inherent in the extruded parts, permanent distortion can occur as the stresses are relieved. The most catastrophic failure would be due to sagging at temperatures where the stiffness or flexural modulus was no longer great enough to maintain dimensional integrity.

With amorphous polymers, such as rigid PVC, the flexural modulus is only slightly reduced with increasing temperature until the glass transition temperature is approached. At that point, there is a precipitous lowering of modulus so it is easy to determine the temperature above which dimensional integrity can no longer be maintained. A convenient measure of this temperature is the Distortion Temperature under Load (DTL), at 264 p.s.i. fiber stress, as determined by ASTM D-648.

Rigid PVC compounds as used in siding, etc., have a DTL of approximately 160^{o}F. It is not surprising that exterior vinyl construction items have been limited to those colors (white and pastels) which do not attain temperatures greater than 140^{o}F. Since deep colored effects are often desired for aesthetic reasons, this is a limitation to the manufacturers of PVC siding and profile extrusions. It would be desirable to be able to raise the distortion temperature of vinyl compounds without adversely affecting any of the other properties which make PVC so acceptable for siding and other exterior construction items. Retention of initial gloss and color is at least as important as retention of initial dimensions.

NEW BLENDING RESINS

The new blending resins, which are the subject of this paper, are modified styrene/acrylonitrile copolymers. They have been designated as 1000 Series™ resins and are in an advanced stage of development. They were designed to combine the ease of fabrication and initial properties of high-impact ABS with good weatherability, measured by retention of appearance and physical properties. These resins are expected to have utility in their own right, as alternatives to ABS where exterior durability is required.

Physical properties representative of 1000 Series resins are presented in Table 1 for Resin X-1003.

TABLE 1. Physical properties of resin X-1003

	Test Method	English Units	Metric (SI) Units
Tensile Strength (yield)	D-638		
(20°F; -7°C)		6000 p.s.i.	41 MPa
(73°F; 23°C)		4700 p.s.i.	32 MPa
(160°F; 71°C)		2800 p.s.i.	19 MPa
Elongation (break)	D-638		
(20°F; -7°C)		20%	20%
(73°F; 23°C)		40%	40%
(160°F; 71°C)		50%	50%
Flexural Modulus	D-790		
(20°F; -7°C)		2.5×10^5 p.s.i.	1.7 GPa
(73°F; 23°C)		2.2×10^5 p.s.i.	1.5 GPa
(160°F; 71°C)		1.8×10^5 p.s.i.	1.2 GPa
Izod Impact (73°F)	D-256	9.0 ft.-lbs./in.	480 J/M
Dart Drop Impact (40 mil)	D-2794		
(20°F; -7°C)		1.2 in.-lb./mil	2.14×10^5 J/M
(73°F; 23°C)		1.8 in.-lb./mil	3.2×10^5 J/M
Distortion Temperature (Annealed, 264 p.s.i.)	D-648	210°F	100°C
Coefficient of Thermal Expansion	D-696	5.0×10^{-5} in./in./°F	8.0×10^{-5} in./in./°C
Flammability	UL-94	HB	-
Specific Gravity	D-792	1.06	-

These properties are all in an acceptable range for construction items, and the exterior durability of the resin is good. Since it is compatible, it is a good blending resin for increasing the DTL of PVC.

PROPERTIES OF PVC BLENDS

The effect of blend ratios on DTL was explored using the simple formulation shown in Table

TABLE 2. Formulation used for PVC/X-1003 blends

Resin X-1003	A
PVC (suspension grade, R.V. 2.12) (1)	100-A
Tin Mercaptide Stabilizer (2)	2.0
Oxidized Polyethylene Lubricant (3)	0.5

(1) SCC 676P - Stauffer Chemical Company
(2) Thermolite 108 - M&T Chemicals
(3) AC-392 - Allied Chemical Corporation

The samples were blended, dried, injection molded and tested according to ASTM D-648. Results are given in Table 3 and in Fig. 1.

TABLE 3. Distortion temperature under load of PVC/Resin X-1003 blends

PVC-X/1003 Ratio	Distortion Temperature (°F)
100/0	162
80/20	168
60/40	174
50/50	180
40/60	186
20/80	193
0/100	200

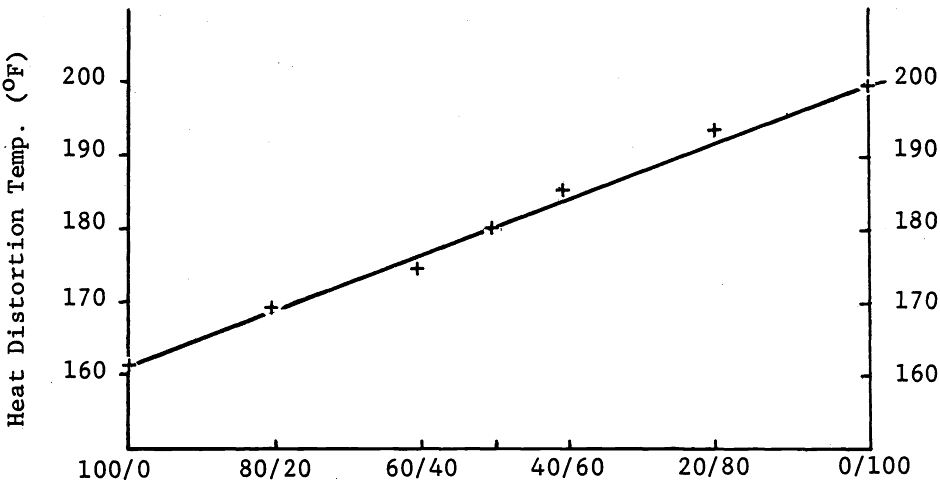

Fig. 1. Distortion temperature of resin blends

The linearity of the data indicates resin compatibility. It is also apparent from the data that a DTL of 175°F can be obtained with an X-1003 content ≥ 50%. For reasons of flammability resistance and economics, it is desirable to have as high a PVC content as possible. Early work was done with X-1003/PVC ratios of 70/30 or 60/40, but work is now being concentrated on 50/50 ratios. The effect on physical properties of altering the resin ratio, using a simple formulation comparable to that given in Table 2, is presented in Table 4. For comparison purposes, the values for a typical commercial siding are also included.

TABLE 4. Physical properties of X-1003/PVC resin blends (73°F)

	Test Method	Units	70/30	50/50	Commercial Siding
Tensile Strength (yield)	D-638	p.s.i.	6000	6900	6400
Flexural Modulus	D-790	p.s.i.	3.1×10^5	3.4×10^5	4.1×10^5
Izod Impact (notched)	D-256	ft.-lbs./in.	12.5	14.2	8.0
Dart Drop Impact (40 mil)	D-2794	in.-lbs./mil	1.9	2.0	2.5
Heat Distortion Temperature (Annealed, 264 p.s.i.)	D-648	°F	190	182	163
Coefficient of Thermal Expansion	D-696	in./in./°F	4.6×10^{-5}	4.3×10^{-5}	3.6×10^{-5}
Flammability	UL-94	-	V-1	V-0	V-0
Density	D-792	g./c.c.	1.16	1.23	1.46
Hardness	D-785	Shore D	75	78	78

These data indicate that acceptable initial properties can be achieved with the blends. It remains to be shown that the exterior durability, in terms of appearance and physical property retention, is satisfactory. Exposure data on pigmented early versions of X-1003 in dark colors provided some expectation that durability would be acceptable. In outdoor tests in both Florida and Arizona, the impact resistance, as measured by dart drop, fell to about 50% of its initial value after 6-12 months and then remained at that acceptable level for the next two years. Similar performance was observed with exposure to laboratory accelerated weathering. These data are represented in Fig. 2 and 3. In all cases, the failures were ductile rather than brittle.

Color retention of pigmented precursor X-1003 compositions in dark colors also had shown acceptable performance after two years in Florida and Arizona.

Several separate studies were carried out. In the first of these, ("A"), the X-1003/PVC ratio was 70/30, and the colors were achieved in large part by using iron oxide pigments. Compositions and performance are listed in Tables 5, 6, and 7.

TABLE 5. Study "A" - Composition of dark colors

Resin Composition	PVC	Blend
X-1003	-	70.00
PVC Homopolymer (1)	100.00	30.00
Stabilizer (2)	2.00	2.00
Lubricant (3)	1.00	1.00
Calcium Stearate	1.20	-
Process Aid (4)	1.00	-
Impact Modifier (5)	6.00	-

Pigment Composition	Red	Brown	Green
Titanium Dioxide	1.70	1.70	1.70
Carbon Black	0.10	0.25	0.04
Red Iron Oxide (6)	1.00	0.85	-
Perylene Red (7)	1.50	-	-
Phthalocyanine Green (8)	-	-	0.04
Yellow Iron Oxide (9)	-	-	2.00

(1) SCC-676P (R.V. 2.12) - Stauffer Chemical Company
(2) Thermolite 108 (Tin Mercaptide) - M&T Chemicals
(3) A.C.-629A (Oxidized Polyethylene) - Allied Chemical Corp.
(4) K-120N - Rohm and Haas
(5) KM-323B - Rohm and Haas
(6) R-1599 - Pfizer
(7) R-6500 - Harmon Color
(8) 15-3100 - American Cyanamid
(9) YO-5087 - Pfizer

TABLE 6. Study "A" - Durability of dark colors

	DART DROP IMPACT RESISTANCE[1]				
Composition	Initial	1 Yr. FL	1 Yr. AZ	1000 Hr. Q-U-V[2]	2000 Hr. Q-U-V
1. PVC Brown	2.5	1.9	1.6	2.0	-
2. 70/30 Brown	1.9	1.2	1.0	1.4	1.1
3. 70/30 Red	1.9	1.2	1.0	1.1	0.9
4. 70/30 Green	1.9	1.2	1.0	1.1	1.0
5. Commercial Siding (Pastel)	2.6	1.9	1.5	1.9	-

1) Expressed as inch-lbs./mil of thickness in 40 mil samples.
2) Cycle is 2 hr. UV; 4 hr. cond., at 50°C.

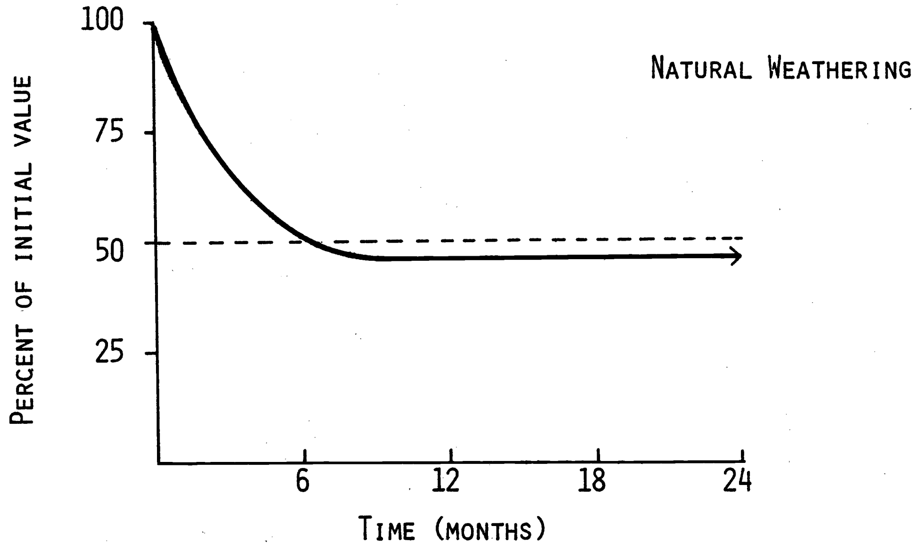

Fig. 2. Loss of dart drop impact resistance - natural weathering

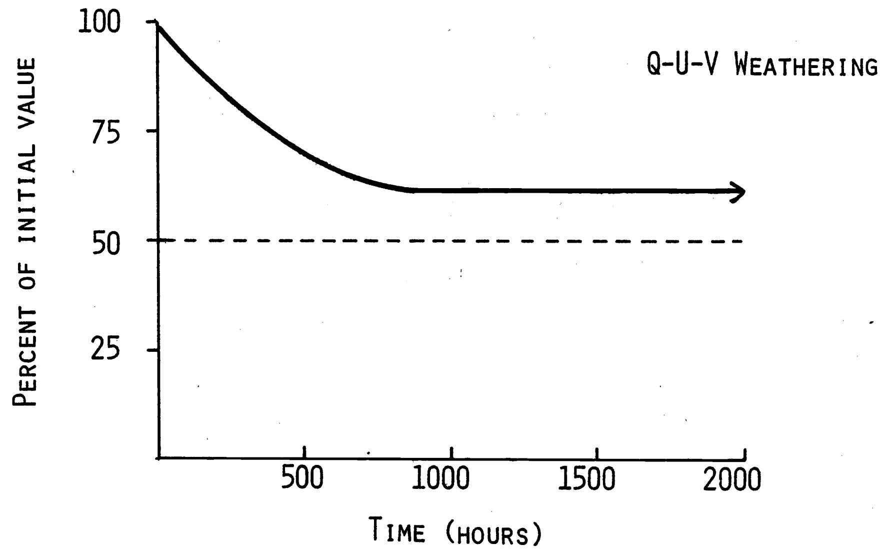

Fig. 3. Loss of dart drop impact resistance - Q-U-V weathering

To investigate exterior durabiltiy, a number of dark-colored plaques were prepared by dry blending, fusing, and compression molding. 70/30 and 50/50 ratios of X-1003/PVC were used and comparison was made with rigid PVC formulations. Colors were obtained using organic pigments, as well as the potentially cheaper inorganic iron oxide pigments which would not normally be used in PVC formulations. Exterior durability was determined through 45°S exposure in both Arizona and Florida. To date, it has been possible to accumulate only one year's actual outdoor exposure. To supplement these data, exposures of the dark formulations have also been made in the Q-U-V Weatherometer, using a cycle that appears to correlate fairly well with outdoor exposure. We have accumulated the equivalent of up to two years (2000 hours) outdoor exposure in this fashion. Durability was measured by the observed changes in dart drop impact resistance and in color and gloss.

TABLE 7. Study "A" - Durability of dark colors

Composition	COLOR CHANGE[1] 1 Yr. FL	1 Yr. AZ	1000 Hr. Q-U-V[2]	2000 Hr. Q-U-V
1. PVC Brown	70.1	25.3	44.7	56.4
2. 70/30 Brown	4.4	1.1	0.6	2.4
3. 70/30 Red	5.0	2.4	1.8	4.8
4. 70/30 Green	6.4	3.8	4.4	10.7

1) Expressed as ΔE (McAdam) units.
2) Cycle is 2 hr. UV; 4 hr. cond., at 50°C.

Although the initial impact resistance of the blended resin composition is not as high as that of a well-formulated PVC compound, the rate of degradation is comparable and, to the extent of exposure to date, retained impact resistance is acceptable. In all cases reported, the impact failure was ductile rather than brittle.

Appearance retention of the blended resin compositions was very encouraging in comparison to the PVC compound.

A second study ("B") was undertaken to further improve the blended resin composition, incorporating the following changes:

- Resin composition was changed to 50/50 X-1003/PVC to improve flame resistance while retaining adequate heat distortion resistance.
- Relative viscosity of the PVC was lowered to achieve better processability of the blend.
- Pigmentation was modified to eliminate iron oxide pigments which are suspect in PVC formulations.
- An U-V absorber was included to improve resistance to surface degradation and to permit low levels of pigment concentration.

TABLE 8. Study "B" - Composition of dark colors

Resin Composition	PVC	Blend
X-1003	-	50.00
PVC Homopolymer (1)	-	50.00
PVC Homopolymer (2)	100.00	-
Stabilizer (3)	2.00	2.00
Lubricant (4)	0.80	-
Calcium Stearate	1.20	-
Lubricant (5)	-	1.00
Process Aid (6)	1.00	-
Impact Modifier (7)	8.00	-
U-V Absorber (8)	1.00	1.00

TABLE 8. Study "B" (Con't)

Pigment Composition	Grey	Red	Brown	Green
Titanium Dioxide	0.40	0.40	0.40	0.40
Carbon Black	0.015	0.02	0.05	0.02
Perylene Red (9)	-	0.30	0.05	-
Isoindolinone Yellow (10)	-	-	0.14	0.025
Isoindolinone Yellow (11)	-	0.30	-	0.15

(1) SCC-614 (R.V. 1.95) - Stauffer Chemical Company
(2) SCC-676P (R.V. 2.12) - Stauffer Chemical Company
(3) Thermolite 137 (Tin Mercaptide) - M&T Chemicals
(4) XL-165 (Paraffin Wax) - American Hoechst Corporation
(5) AC-392 (Oxidized Polyethylene) - Allied Chemical Corp.
(6) K120N - Rohm and Haas
(7) KM 323B - Rohm and Haas
(8) Tinuvin P - Ciba-Geigy Corporation
(9) R-6500 - Harmon Color
(10) 3RLT - Ciba-Geigy Corporation
(11) 2GLT - Ciba-Geigy Corporation

This study is so recent that no significant outdoor exposure data have been collected. We have relied on accelerated weathering in the Q-U-V Weatherometer for an assessment of durability as shown in Table 9.

TABLE 9. Study "B" - Durability of dark colors

Composition	Dart Drop Impact Resistance[1] Initial	Dart Drop Impact Resistance[1] 1000 Hr. Q-U-V	Color Change[2] 1000 Hr. Q-U-V	45^o Gloss[3] Initial	45^o Gloss[3] 1000 Hr. Q-U-V
Grey PVC	2.3	1.6	13.2	38	25
Grey Blend	2.0	1.2	8.7	46	44
Red PVC	2.4	1.6	25.6	45	36
Red Blend	1.8	1.3	0.6	44	41
Brown PVC	2.6	1.7	28.1	31	25
Brown Blend	2.1	1.3	1.2	46	41
Green PVC	2.8	1.8	16.1	47	39
Green Blend	2.1	1.2	3.4	49	41

1) Expressed as inch-lbs./mil of thickness in 40 mil samples.
2) Expressed in $\triangle$E (McAdam) units.
3) Expressed as percentage.

It is apparent that the dart drop impact resistance of the resin blend composition is higher initially than in Study "A" but deteriorates at about the same rate as the compositions in Study "A", or in the corresponding PVC compositions. Our experience with similar systems suggests that additional exposure will result in limited additional degradation.

Gloss and color retention of the resin blend compositions are much improved over those of the corresponding PVC compositions.

CONCLUSION

This polyblend approach appears to hold promise as a method of achieving the durability required in dark colored profile extrusions for exterior construction items.

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