

Status of Investigations for Improving Weatherability of Linear Polyethylene and Copolymers

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INTRODUCTION

High-density polyethylenes possess a combination of favorable physical properties, chemical resistance, and economic characteristics which render them extremely versatile and suitable in a wide variety of applications. During the last few years particular interest has been focused on the widespread use of high-density resins in products designed for outdoor applications. Resins intended for this type of use require special attention because they are susceptible of degradation from sunlight and other outdoor weathering conditions.

Sunlight on unpigmented high-density polyethylene without added ultraviolet absorber is the most severe of the outdoor conditions. Sunlight is essentially a form of radiant energy, the intensity of which varies inversely with wavelength.¹ Ultraviolet light, consisting of relatively short wavelengths (290 to 400 $m\mu$), has extremely high energy which can cause a break in some of the chemical bonds found in linear polyethylene resins.

Early in the development of high-density polyethylene, it became apparent that the serviceability of this resin in outdoor applications would be severely limited unless the deteriorative effects of ultraviolet on high-density polyethylene were eliminated or significantly reduced by some method of stabilization.

METHODS OF STABILIZATION

Our laboratory approached this problem by investigating three different methods of stabilization. The first involved the addition of commercially available ultraviolet absorbers to the unpigmented resin. A screening of several absorbers yielded three as being most promising: 2-hydroxy-4-methoxybenzophenone, commercially marketed under the trademark Cyasorb (UV-9), 2,2'-dihydroxy-4-*n*-octoxybenzophenone, trade-

marked Cyasorb (UV-314), and 4-*tert*-butylphenyl salicylate, identified as (TBS). These ultraviolet absorbers were used throughout our entire testing program.

The second method of stabilization investigated was the use of pigments. Sixteen pigments and the effectiveness of each in concentrations of 0.25, 1, and 5% were tried. Since pigments have the ability to absorb various wavelengths they might also be expected to protect polyethylene resin from ultraviolet degradation by screening out the harmful wavelengths.

The third method of stabilization investigated was the use of ultraviolet absorbers in combination with pigment in the resin. Of particular interest was the determination of whether, in highly pigmented materials, a reduction in pigment level could be made by the incorporation of a stabilizer. Also of interest was whether there was an additive or synergistic effect of having both stabilizer and pigment as opposed to having only one or the other.

The relative resistance to degradation by ultraviolet of resins having densities of 0.950 and 0.960 g./cc. was also studied so that the better resin could be selected for outdoor applications. The effect of melt index on stability was also investigated in the homopolymer resins (density 0.960). Resins of various melt index were employed in this phase of the study.

PROCEDURE

Unpigmented and pigmented high-density linear polyethylene homopolymer resins in flake form, with and without added ultraviolet absorber,* having melt indices of 0.7, 2.5, and 5.0 decigrams

* All homopolymer and copolymer resins used in this study contained Ionol (di-*tert*-butyl-*p*-cresol) in 0.03% concentration, which was added to the resins prior to our processing. "Added absorber" refers to the addition of UV-9, UV-314, or TBS.

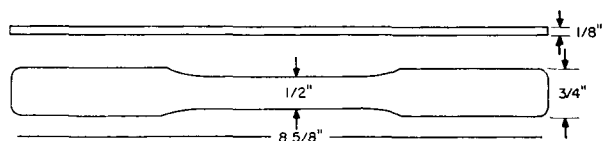


Fig. 1. Tensile bar dimensions.

per minute were injection molded as standard ASTM-type tensile bars, as shown in Figure 1. These samples were exposed in an Atlas XW-type Weatherometer with the "Sunshine" carbon arc and Corex D Filters so that the radiation would be as near that of sunlight as possible. The energy distribution curves of sunlight and this Weatherometer radiation are shown in Figure 2. Every 200 to 250 hr. samples were removed and examined for discoloration and surface cracking. Samples were then tested for tensile strength and per cent elongation in accordance with ASTM Method D638-58T, on an Amsler Tensile Testing Machine at a rate of 10 inches per minute. This high pulling rate was used so that the elongation at break could be determined. The melt index was also determined, for a knowledge of the effect of ultraviolet degradation on flow.

The tensile strength, elongation, and melt index were plotted against hours of exposure in the Weatherometer. During these studies surface cracking (exposed samples which exhibited surface cracking also were brittle and easily broken by hand) of the exposed samples was observed to occur at approximately the same time as a significant decrease in physical properties. Such observations became a method of rapidly screening

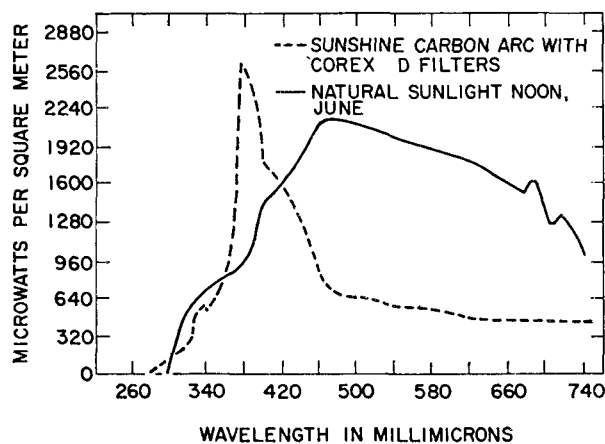


Fig. 2. Energy distribution of sunlight and Weatherometer radiation.

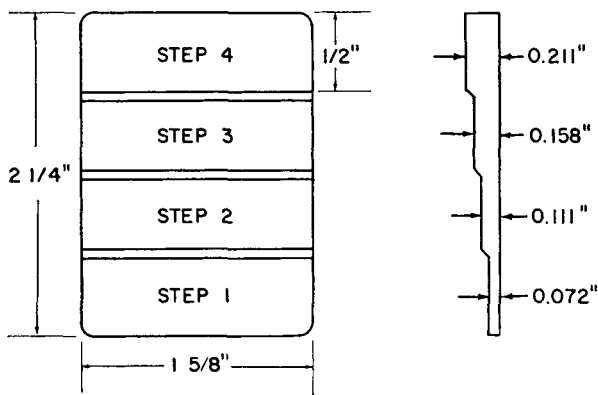


Fig. 3. Step chip dimensions.

a large number of linear polyethylene formulations for their resistance to ultraviolet radiation.

Step chip specimens used for this phase of the study, described in Figure 3, had four levels of varying thickness. Test data obtained on these samples were also used, to compare the effect of ultraviolet on thin and thick sections of molded parts.

Step chip specimens injection molded from high-density linear polyethylene homopolymer having a density of 0.960 g./cc. and melt index of 0.7 dg./min. and polyethylene copolymer of density 0.950 g./cc. and melt index of 0.8 dg./min. were used in our pigment studies. These resins were pigmented in concentrations of 0.25, 1, and 5% with sixteen different pigments (Table I). These pigments are commonly used in industry. In addition, a formulation consisting of 4% white plus one quarter part of each of the pigments was prepared for a study of the stability of opaque pastel colors and the effectiveness of white pigment as an ultraviolet absorber. Ultraviolet absorbers UV-9 and UV-314, as discussed earlier, were also added in 0.25% concentration to formulations containing 0.25% pigment.

TBS was tested in 0.5 and 1% concentrations. UV-9 in 0.25% concentration was also incorporated in formulations containing 5% pigment. Unpigmented homopolymer and copolymer samples without added stabilizer were used as controls. All formulations were prepared by mixing for 15 min. on a two-roll mill at a temperature of 350°F. The resultant blanket was stripped from the rolls, cut into strips approximately 12 in. by 2 in., ground into small particles, and injection molded as step chips on a Mini-Jector at a temperature of 420°F.

Laboratory testing was conducted in an Atlas XW-type Weatherometer as explained previously.

TABLE I
Pigments

Color	Type	Supplier	Supplier's description
Red	Cadmium sulfide mercuride	Imperial Paper Color Corp.	Mercadium red X2669
Red	"	"	Mercadium Red X2670
Orange	Cadmium sulfide selenide	S. Doggett, Inc.	Cadmium red #408
Yellow	Cadmium sulfide	"	Cadmium yellow lemon #475
Primrose yellow	"	General Color Co.	Cadmium primrose yellow
Green	Chlorinated copper phthalocyanine	Collway Colors	Permanent green R2453
Blue	Ultramarine	Calco Chemical Co.	Ultramarine Blue 59-4930
Blue	Copper phthalocyanine	Whittaker, Clark and Daniels	Plastic blue 1560
Cobalt blue	Cobalt	Drakenfeld	Cobalt blue 4158
Peacock blue	Copper phthalocyanine	Max Marx Co.	Fast peacock blue
Purple	1,2-dihydroxy anthraquinone on aluminum hydrate	Harmon Color Works	Alizarin Maroon MV-7013
Purple	Linear quinacridone	E. I. du Pont de Nemours Co.	Monastral purple
Brown	Iron oxide	R. Coulstan Co.	Burnt sienna #1015
Raw umber	"	"	Raw umber #1044
Black	Carbon (channel black)	Godfrey L. Cabot, Inc.	Monarch 74
White	Titanium dioxide	Titanium Pigments Co.	Titanox RA-NC

Step chips were inspected about every 100 hr. for evidence of stress cracking, crazing, and discoloration. The first evidence of cracking was considered failure.

Similar step chips were subjected to conditions of outdoor weathering on an open rack facing south and inclined at an angle of 45° in Phoenix, Arizona, and in Summit and Newark, New Jersey. The Arizona location was selected for exposure because this part of the United States receives the maximum radiation—approximately 200,000 Langley units compared with the New England area, which receives about 120,000 Langley units per year. (A Langley unit is defined as 1 g.-cal./cm.² or 3.69 B.t.u./ft.².) This testing substantially accelerated the accumulation of test data.

A complete set of sample step chips representing all specimens subjected to outdoor weathering and ultraviolet radiation in the XW-type Weatherometer were kept as controls under cover in a dark area of a room at temperatures of 70 to 80°F.

DISCUSSION OF RESULTS

As shown in Figure 4, the melt index, tensile strength (at break), and elongation (at break) decreased with increasing exposure time in the Weatherometer. These particular curves show the degradation effect of ultraviolet on unpigmented homopolymer of 0.960 density and 5.0 melt index,

injection molded as tensile bars. The curves give an indication regarding the physiochemical transformations which take place in the resin as a result of exposure.

It is generally believed that physical property degradation is caused by a scission in the molecular chain and by crosslinking, which occur simultaneously but to different degrees at any one time. The properties of the resin after exposure depend on whether scission or crosslinking is predominant. As shown in Figure 4 there is initially a moderate increase in melt index, tensile strength, and tensile

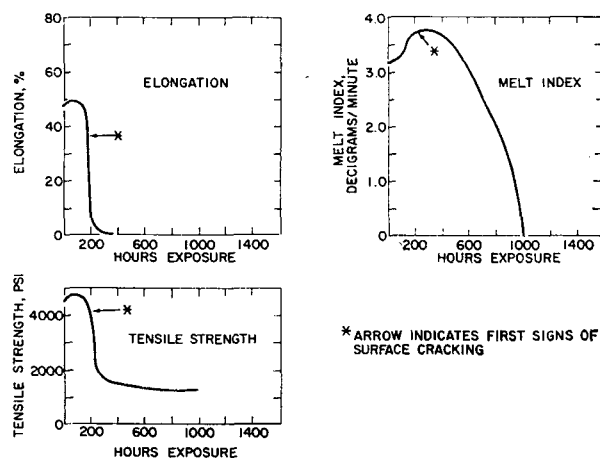


Fig. 4. Effect of ultraviolet radiation on physical properties of linear polyethylene.

elongation. This may be due to chain scission initially occurring to a greater degree than cross-linking and, possibly, to an annealing effect, which would tend to increase crystallinity.

The curves then show a decrease in these properties. During the fall-off in these properties, the resin became brittle and surface cracking occurred, indicating that the material may have been highly crosslinked. The first signs of surface cracking were evident after 200 to 250 hr. of exposure in the XW-type Weatherometer.

Melt Index

It was determined that resins of low melt index and higher molecular weight had greater resistance to ultraviolet degradation. Figure 5 shows the relative decrease in tensile strength (at break) of unpigmented homopolymers with no added stabilizer and having melt indices of 0.7, 2.5, and 5.0. The decrease in tensile strength on Weatherometer exposure is significantly greater with the 5.0 melt index resin than with the 0.7 melt index material. The homopolymer of 2.5 melt index is intermediate in behavior.

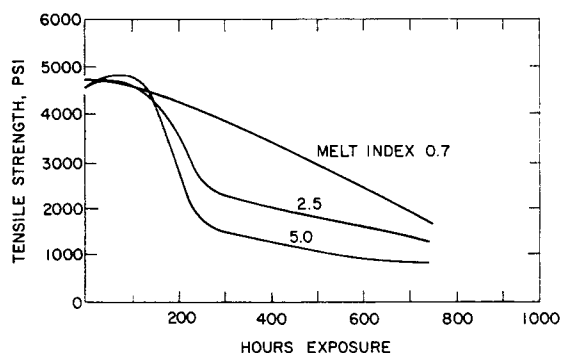


Fig. 5. Effect of melt index on resistance of linear polyethylene to ultraviolet.

Density

The superior resistance to ultraviolet of the higher density homopolymer resin became apparent during our studies. Figure 6 shows the relative time in hours to failure in the Weatherometer of step chips injection molded from 0.960 and 0.950 density materials. Both resins contain 1% pigment, as indicated, but had no added ultraviolet absorber. It can be seen that the higher density homopolymer had greater than three and one-half times the ultraviolet resistance of the lower density copolymer resin in the red pigmented material, and somewhat better ultraviolet resistance in almost all other pigmented

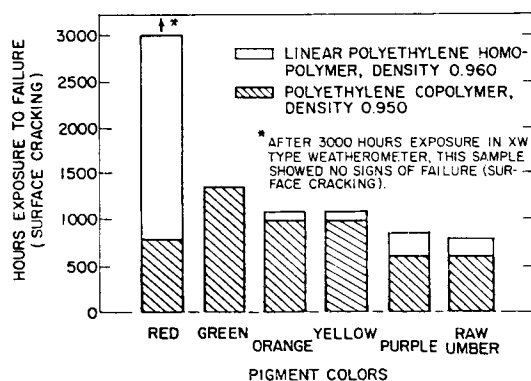
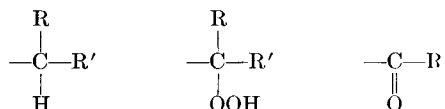


Fig. 6. Effect of density on resistance of polyethylene to ultraviolet.

samples. These results are typical of a general trend occurring in this study.

This trend is possibly due to the relatively large number of tertiary hydrogen groups on the copolymer molecules as compared with the linear polyethylene homopolymer molecules. These tertiary groups may be readily oxidized,² causing chain scission and an increase in the carbonyl content of the resin as follows:



Another factor may be the crystallinity of both resins. The homopolymer of 0.960 density is 93% crystalline while that of the copolymer, of 0.950 density, is 87%. Oxygen cannot readily penetrate the crystalline regions, owing to the close alignment of the molecules. However, in the amorphous regions, the reverse is true. Molecules in this region are in a random order, leaving spaces that can be attacked by oxygen and resulting in oxidation and degradation of the polymer. Since the copolymer has a greater amorphous region than the homopolymer, it would be expected to be less stable and have poorer resistance to ultraviolet.

Stress and Strain

Various outdoor field applications have indicated that a relationship exists between the stresses molded into a particular part and its subsequent ultraviolet stability.

Although our laboratory did not specifically explore the effect, it became evident in this study that for any particular formulation there was a difference in time to failure, depending on whether the specimen was molded as a step chip or a tensile

bar. An example of this was noted in specimens molded from unpigmented homopolymer of 0.7 melt index and exposed in the Weatherometer. The tensile bars exhibited surface cracking after only 250 hr. of exposure, while the step chips required approximately three times the exposure—800 hr. to fail. The tensile bar samples contained greater molded-in stresses, because of their size and shape.

These results and those obtained in the density study suggest that proper annealing of the part, to relieve molded-in stress and strains, tends to increase resistance to ultraviolet and prolong outdoor serviceability. The data also suggest the importance of mold design and molding conditions.

Thickness

The effect of part thickness on ultraviolet stability became apparent during our extensive studies with step chip samples. As shown previously in Figure 3, the step chips had four levels of thickness varying from 0.072 in. at the thinnest step to 0.211 in. at the thickest. It was noted in almost all samples that failure occurred much more quickly in the thinnest sections. A typical example of this is shown in Table II. This table shows the hours of exposure required for failure of the thickest and thinnest parts of step chips molded from linear polyethylene homopolymer having a melt index of 0.7 and pigmented with monastral purple in various concentrations. Some formulations contained ultraviolet absorber.

TABLE II
Effect of Part Thickness on Ultraviolet Stability of Linear Polyethylene

Monastral purple pigment conc., %	Stabilizer and concn., %	Step no.	Exposure to failure, hrs.
0.25	—	1, 2, 3	800
		4	1250
0.25 + 4% white	—	1, 2	900
		3	1250
		4	1850
0.25	0.25 UV-9	1, 2, 3	900
		4	1250
1	—	1, 2	900
		3	1050
		4	1550
5	—	1, 2	2000
		3	2600
		4	>3000
5	0.25 UV-9	1	1400
		2	1550
		3, 4	>3000

Ultraviolet Absorbers

Test data obtained by exposure of unpigmented step chips in the Weatherometer indicated that ultraviolet absorber UV-314 at a concentration of 0.25% increased the resistance of unpigmented copolymer resin more than three and one-half times, from 800 to longer than 2900 hr., while TBS in concentrations of 0.5 and 1.0% increased the ultraviolet resistance approximately two and one half times, from 800 to 2050 hr. UV-9 at a concentration of 0.25% was somewhat less effective than these two stabilizers; however, it increased the resin's life from 800 to 1000 hours. Although UV-314 and TBS were considered very effective in preventing physical property degradation, they exhibited some discoloration due to their slight absorption in the low wavelength region of the visible spectrum. This can be eliminated by proper pigmentation. Formulations containing UV-314 will discolor to a light yellow immediately on processing and must be properly pigmented during formulation. TBS will not show any discoloration on processing but after several hours of exposure in the Weatherometer will turn slightly yellow. Both these ultraviolet stabilizers require careful consideration in pigmentation, to mask the slight yellowing effect. As a general rule, the light colors (except yellow and pastel colors) such as blue, beige, and purple will require special attention to pigmentation. Darker colors such as red, green, raw umber, orange, and brown will readily mask the discoloration.

UV-9 generally did not have any effect on discoloration.

Pigments

The studies concerning the use of only pigments for increasing the ultraviolet resistance of linear polyethylene homopolymer indicated that certain pigments in low concentration may have a tendency to photosensitize the resin. As shown in Table III, pigments such as green, ultramarine and copper phthalocyanine blue, orange, iron oxide brown and raw umber, red and alizarin lake purple in concentrations of 0.25% actually decreased the resistance of the resin to ultraviolet, failing after 3 months of exposure to Arizona weathering, compared with 6 months' exposure for unpigmented resin having no added ultraviolet absorber. In low pigment concentrations the pigment may accelerate degradation. However, at high pigment levels only the surface of the resin will degrade and the excess

amount of pigment will mask the inner sections and retard any further degradation.

TABLE III

Pigments in Low Concentration (0.25%) That Have a Tendency to Decrease Ultraviolet Stability of Linear Polyethylene

Pigment	Failure in Arizona, months
None	6
Red	3
Orange	3
Green	3
Blue (ultramarine)	3
Blue (copper phthalocyanine)	3
Purple	3
Brown	3
Raw umber	3

Cobalt blue, monastral purple, and yellow pigments in 0.25% concentration had no effect on the resin's resistance to ultraviolet. Step chips molded from these materials failed after 6 months of exposure in Arizona. White, peacock blue, and channel black pigments in 0.25% concentration increased the resistance of the resin to ultraviolet. Step chips molded from the white- and peacock-blue-pigmented materials failed after 9 months' exposure to Arizona weathering, while the sample pigmented black has not yet failed after 12 months.

As shown in Table IV, by increasing the pigment concentration up to 5% with pigments such as green, orange, peacock blue, monastral purple, and red, the ultraviolet stability of the resin was increased. At the 5% level, the samples pigmented with green, red, peacock blue, monastral purple, and black have withstood 12 months of exposure without failure.

An increase in pigment concentration of ultramarine, copper phthalocyanine, and cobalt blue, yellow, brown, white, purple and raw umber from 0.25 to 5% did not cause a corresponding increase in ultraviolet resistance of the linear polyethylene homopolymer resin.

Channel black pigment in concentrations of 0.25 to 5%, as expected, performed the best; the samples show no signs of degradation after 1 yr. of Arizona exposure or 3000 hr. of exposure in the Weatherometer.

In the Newark and Summit areas of exposure, no surface cracking in any of the samples tested has occurred since the first samples were exposed 2 yr. ago. With respect to pigment color stability, it was generally found that black, yellow, orange,

TABLE IV
Effect of High Pigment Loading on Ultraviolet Stability of Linear Homopolymer

Pigment	Failure in Arizona, months	
	At 0.25% concn.	At 5.0% concn.
Red	3	>12
Orange	3	9
Green	3	>12
Peacock blue	9	>12
Monastral purple	6	>12
Black	>12	>12

green, white, and red were the most resistant to discoloration; while blue, purple, brown, and raw umber were the least.

As shown in Table V, the addition of 4% white pigment to 0.25% of some colored pigments increased the resistance of the homopolymer resin to Arizona exposure. This was evident in pigment colors such as orange, brown, raw umber, red, alizarin lake purple, monastral purple and cobalt blue. In other pigments such as green, ultramarine, copper phthalocyanine, and peacock blue, and yellow, the addition of 4% white had no effect.

TABLE V

Effect of High White Pigment Loading on Ultraviolet Stability of Linear Polyethylene Homopolymer Resin

Pigment	Failure in Arizona, months	
	At 0.25% concn.	Addn. of 4% white to 0.25% pigment
Red	3	6
Orange	3	6
Cobalt blue	6	>9
Purple	3	6
Monastral purple	6	9
Brown	3	6

Pigment plus Ultraviolet Absorber

In all pigment systems, as shown in Table VI, the addition of 0.25% UV-314 or 1% TBS increased the resistance of the polyethylene copolymer two to greater than threefold, as compared with unpigmented and pigmented resin without added stabilizer. In almost all pigmented samples except yellow, raw umber, and monastral purple the addition of 0.25% UV-314 was more effective in increasing the ultraviolet resistance of the copolymer resin than TBS in 1% concentration. The addition of 0.5% TBS increased the ultraviolet resistance of all pigmented samples but was not as effective as 1% TBS. UV-9 in 0.25% concentration

TABLE VI
Effect of Ultraviolet Absorbers on Ultraviolet Stability of
Copolymer Resin Containing 0.25% Pigment

Pigment	Hours to failure in XW-type Weatherometer				
	Ultraviolet absorber and concn.				
	None	0.25% UV-314	1.0% TBS	0.5% TBS	0.25% UV-9
None	800	>2900	2050	2050	1000
Red	800	>2900	2050	1550	1000
Orange	800	>2900	2250	1700	1100
Yellow	800	>2900	>2900	>2900	1100
Green	700	>2900	1550	1400	1100
Blue (ultra- marine)	600	2250	2150	1250	800
Blue (phthalo- cyanine)	600	1850	1550	1250	700
Cobalt blue	800	2900	1700	1250	1100
Peacock blue	800	2050	1700	1250	800
Purple	1250	2050	1700	1100	1000
Monastral purple	800	2050	2050	1400	800
Brown	700	2050	1700	1100	700
Raw umber	800	1000	1400	1100	700
White	700	2550	2250	1700	1000

was the least effective in increasing ultraviolet stability.

The addition of 0.25% ultramarine, copper phthalocyanine, cobalt and peacock blue, alizarin lake purple, monastral purple, brown, raw umber, and white to unpigmented resin, containing 0.25% UV-314, had a deteriorative effect, decreasing the ultraviolet resistance of the copolymer. Continued exposure of other pigmented samples will determine whether there is a synergistic effect of these pigments and stabilizer.

The addition of 0.25% orange, yellow, ultramarine blue, and white pigments to unpigmented resin containing 1.0% TBS showed an increase in ultraviolet resistance, indicating that there was an additive effect of pigment and 1.0% TBS absorber. Pigments such as green, copper phthalocyanine, cobalt and peacock blue, alizarin lake purple, brown, and raw umber had a deteriorative effect, while red and monastral purple had no effect.

The addition of 0.25% red, orange, green, ultramarine, copper phthalocyanine, cobalt and peacock blue, alizarin lake purple, monastral purple, brown, raw umber, and white to unpigmented copolymer resin stabilized with 0.5% TBS had a deteriorative effect on ultraviolet stability, while yellow had an additive effect and increased the resistance of the copolymer resin.

The addition of pigment to unpigmented resin stabilized with 0.25% UV-9 did not significantly

improve or change the resins' resistance to ultraviolet.

CONCLUSIONS

From this study it may be concluded that, for optimal outdoor serviceability with respect to retention of elongation, tensile strength, and melt index properties of a particular molded item, the following steps are necessary:

1. A resin having high density, such as 0.960, and as low a melt index as processing allows should be selected.

2. The molded item should be designed to minimize the formation of molded in stresses and strains. Thin sections are particularly undesirable.

3. For applications that do not require color stability, ultraviolet absorber UV-314 in 0.25% concentration or TBS in 1% concentration should be incorporated in the formulation, to give optimal protection against surface cracking and decrease in elongation, tensile strength, and melt index properties. When both color stability and physical property protection are required, proper pigmentation is necessary to mask the yellowing effect of these stabilizers. If color stability is of prime importance, UV-9 may be used with any combination of pigments.

4. An ultraviolet absorber should be incorporated in the resin when pigments such as green, ultramarine and copper phthalocyanine blue, orange, iron oxide brown and raw umber, red, and alizarin lake purple are to be used in low concentration.

5. Pigments such as green, orange, peacock blue, monastral purple, red, and black in high concentrations will prolong the outdoor weatherability of a given product.

6. In all cases the best weatherability for a given product may be obtained by proper pigmentation, use of an ultraviolet absorber such as previously mentioned, or a combination of pigment and ultraviolet absorber and low levels of molded-in stress and strain.

When these factors are accounted for, the actual outdoor serviceability of a particular molded item will depend on the location of exposure, extent to which the product is left exposed, and the end use of the molded item.

Molded parts used commercially outdoors are expected to last considerably longer than indicated by the test specimens employed in this study, since these specimens were exposed to the most severe conditions.

We wish to thank Atlas Electric Devices Company, Chicago, Illinois, for permission to use the energy distribution curves shown in Figure 2.

References

1. Hardy, W. B., and R. A. Coleman, *Proc. Amer. Assoc. Textile Chemists Colorists, Perkin Centennial*, 69-75 (1956).
2. Stephens, H. N., *J. Am. Chem. Soc.*, **57**, 2380 (1935).

Synopsis

In an attempt to extend the outdoor serviceability of items molded from linear polyethylene and copolymers, three ultraviolet absorbers, namely, Cyasorb UV-9 (2-hydroxy-4-methoxybenzophenone), Cyasorb UV-314 (2,2'-dihydroxy-4-*n*-octoxybenzophenone), and TBS (4-*tert*-butyl phenyl salicylate), sixteen different pigments, and combinations of both ultraviolet absorber and pigment were investigated. Injection-molded test specimens were employed in this study. The laboratory source of radiation to which these samples were exposed was an Atlas XW Weatherometer. Similar samples also were exposed at various outdoor locations including Phoenix, Arizona, Summit, New Jersey, and Newark, New Jersey, to utilize practical conditions of outdoor weathering. During these weathering studies surface cracking was observed as occurring at approximately the same time as a significant decrease in tensile strength, elongation, and melt index. Such observations became a method of rapidly screening a large number of formulations for resistance to ultraviolet radiation. For optimal outdoor serviceability with respect to retention of elongation, tensile strength, and melt index properties of molded items, the following steps are necessary. A high-density resin having as low a melt index as possible is selected. The molded item is designed to minimize the formation of molded-in stresses and strains. Proper selection of UV absorbers, pigments, and combinations of both are made. Pigments such as green, orange, peacock blue, monastral purple, red, and black, in high concentrations, will prolong the outdoor weatherability of a given product.

Résumé

Afin de favoriser l'emploi à l'extérieur d'objets moulés formés à partir de polyéthylènes linéaires et de copolymères, on a étudié l'influence de 3 absorbers d'ultraviolet et notamment le Cyasorb UV-9 (2-hydroxy-4-méthoxy-benzophénone), le Cyasorb UV-314 (2,2'-dihydroxy-4-*n*-octoxy-benzophénone) et le TBS (salicylate de 4-*tert*-iobutyl phényle), 16 pigments différents, et des différentes combinaisons entre ces pigments et les absorbers d'UV. Les échantillons qui ont été testés proviennent d'objets obtenus à partir de montage par injection. La source de radiations au laboratoire à laquelle ont été soumis ces échantillons provient du "weatherometer" Atlas type XW. Des échantillons identiques ont également été exposés dans différentes stations comme Phoenix, Ariz., Summit, N.J., et Newark, N.J., afin d'utiliser des conditions pratiques de

résistance aux intempéries. Au cours de ces études de vieillissement aux intempéries, on observe des craquelures, celles-ci apparaissent approximativement en même temps qu'une diminution dans la force de tension, d'élongation et dans l'indice de ramollissement. De telles observations nous permettaient ainsi de déterminer de nombreuses formules donnant des produits résistants aux radiations UV. Pour une utilisation optimum à l'extérieur d'objets moulés, c.à.d. sans grande variation dans les propriétés tels que élongation, force de traction et indice du ramollissement des produits fondus, les conditions suivants sont requises: choisir une résine à haute densité et possédant un indice de ramollissement le plus bas possible; le produit fondu doit être choisi en vue d'éviter la formation de tension interne du produit fondu; une sélection appropriée d'absorbants UV, de pigments et de la combinaison de ces 2 devra être faite. Les pigments tels que le vert, l'orange, le bleu de paon, le pourpre cardinal, le rouge et le noir en concentrations élevées prolongeront la résistance aux intempéries d'un produit donné.

Zusammenfassung

Um die Verwendbarkeit von Gegenständen aus linearem Polyäthylen und Copolymeren im Freien zu verbessern, wurden drei Ultraviolettabsorber, nämlich Cyasorb UV-9 (2-Hydroxy-4-methoxybenzophenon), Cyasorb UV-314 (2,2'-Dihydroxy-4-*n*-octoxybenzophenon) und TBS (4-*tert*-Butylphenylsalicylat), sechzehn verschiedene Pigmente und Kombinationen von Pigment und Ultraviolettabsorber untersucht. Bei dieser Untersuchung wurden Spritzguss-Testproben verwendet. Die im Labor für die Proben verwendete Bestrahlungsquelle war ein Atlas XW Weatherometer. Ähnliche Proben wurden auch an verschiedenen Orten im Freien exponiert, nämlich in Phoenix, Ariz., Summit, N.J. und Newark, N.J., um praktische Bedingungen der Bewitterung im Freien zu verwenden. Während dieser Bewitterungsversuche wurde eine Oberflächenrissebildung beobachtet, die ungefähr gleichzeitig mit einer merklichen Abnahme der Zugfestigkeit, der Dehnbarkeit und des Schmelzindex auftrat. Diese Beobachtungen wurden zu einer raschen Beurteilung der Beständigkeit einer grossen Anzahl von Ansätzen gegen Ultraviolettbestrahlung entwickelt. Für eine optimale Verwendbarkeit im Freien in Hinblick auf eine Beibehaltung der Dehnbarkeit, der Zugfestigkeit und des Schmelzindex von Gegenständen sind folgende Punkte zu beachten: es soll ein Harz mit hoher Dichte und einem möglichst niedrigen Schmelzindex ausgewählt werden; der Gegenstand soll so gebaut sein, dass die Bildung von Spannungen und Deformationen beim Spritzguss auf ein Minimum beschränkt ist; eine geeignete Auswahl der UV-Absorber, Pigmente oder Kombinationen von beiden soll getroffen werden. Pigmente wie Grün, Orange, Pfauenblau, Purpur, Rot und Schwarz in hohen Konzentrationen verlängern die Wetterbeständigkeit eines Produktes im Freien.

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