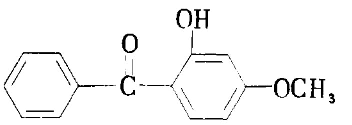
Improved Light Stability for Plasticized Poly(vinyl Chloride)

P. R. GRAHAM, J. R. DARBY and B. KATLAFSKY
Organic Chemicals Division, Monsanto Chemical Co., St. Louis, Mo.

Poly(vinyl chloride) is unstable upon exposure to heat and ultraviolet light. This instability is evidenced by the rapid discoloration and serious stiffening apparent after exposure to processing temperatures or to outdoor weathering (*2,6,9*). Moreover, this instability is sometimes aggravated by the presence of plasticizers and other additives which are themselves prone to degradation (*4*). It is imperative then, that for successful application employing poly(vinyl chloride), PVC, the formulation must contain additives capable of certain specific chemical reactions with the resin, plasticizer, decomposition products and/or oxygen to prevent discoloration and loss of physical properties during processing or outdoor use.

A new type of PVC stabilizer, when used in conjunction with certain other stabilization systems, protects PVC for a period far beyond that obtained with these systems alone. This type of stabilizer is an organic ultraviolet light screening agent which absorbs high-energy ultraviolet light before it can catalyze the undesirable degradation reactions. It is assumed to function by absorbing the high energy radiation and emitting it in the form of heat (*1*). There is strong evidence that these stabilizers have some chemical stabilization effect in addition to their light-screening activity.

The benzophenone structure with one or more hydroxy groups substituted in the ortho positions provides excellent light screening efficiency. The greater portion of this work involves the testing of the compound:



2-Hydroxy-4-methoxybenzophenone (2H4MB)

Among the earliest successful commercial PVC stabilizers were the lead salts. These compounds, consisting of lead stearate, basic carbonate of white lead, lead silicate, and others, were believed to function by reacting with hydrochloric acid which is formed during the degradation of the resin, thereby lessening the alleged deleterious catalytic activity of the acid (*8,14*). These products are used to a large extent in electrical formulations where electrical performance is essential and good clarity is not required. Additional stabilizers have been developed which more than double the stability afforded by these lead compounds.

The discovery of the "epoxy-cadmium" system for PVC stabilization was a significant advance (*3,10,12*). The term "epoxy-cadmium" system is used here to signify the synergistic mixture of a compatible epoxy compound, a barium-cadmium organic salt, and an antioxidant such as triphenyl phosphite. It is thought that the increased effectiveness of this combination is based on a complex series of reactions involving the scavenging of hydrochloric acid, termination of free radicals, elimination of conjugated double bonds, retardation of oxidation effects, and the subsequent complexing of barium or cadmium insoluble salts (*11*). This system (or varieties thereof) is probably the most widely used by the industry for nonelectrical uses.

PROCEDURES AND MATERIALS

Preparation of Film and Sheet Specimens. The resin, plasticizer, stabilizers, and/or fillers were premixed, milled at 175° C. for 5 minutes, sheeted off, and pressed into 0.040-inch sheets. These sheets were exposed in the artificial weathering units. For outdoor exposure specimens, similar formulations were dry blended, milled, and calendered to a film thickness of 0.004 inch.

Exposure of Specimens. The 0.040-inch sheets were exposed in the Model X1-A Weatherometer adjusted to develop black panel temperatures of 145° F. The instrument was set to rotate once every 2 hours and to allow an 18-minute water spray period during each cycle. The data presented in the figures are those from the films exposed in the Weatherometer. At Hazelwood, Mo., the 0.004-inch films were exposed outdoors on unbacked aluminum racks inclined 45° from the horizontal and facing south.

Evaluation of Exposed Specimens. Small samples of the exposed sheets were removed from the artificial light units at 250-hour intervals and allowed to remain in the dark for at least 24 hours to ensure maximum development of discoloration. This discoloration was measured relatively with a Photovolt Model 610 reflection meter using a blue filter with maximum transmission at 415 μ. The standard used was magnesium oxide in a quartz cuvette and was considered as 100% reflectance. The standard was used to back the transparent and translucent specimens during measurement.

The Model TTC Instron tester was used to measure the physical properties on specimens removed at various intervals from the light units and exposure racks. Because of the limited exposure space, relatively small specimens were used, necessitating the construction of a special die small enough to cut numerous specimens from the exposed sheet. (See Figure 1 for the shape and dimensions of the die.) A die of this size was valuable for following the abrupt changes in the mechanical behavior of film after exposure to heat and light. Although limiting the accuracy to some extent, this micro test gave relative results of satisfactory reproducibility. The crosshead speed was maintained at 10 inches per minute. Full scale load was set at 10 pounds for the 0.040-inch sheeting and 2 pounds for the 0.004-inch film.

Ultraviolet Spectra Studies. The ultraviolet spectra of a series of potential light-screening agents were measured with a Cary Model 11 double-beam recording spectrophotometer. The materials were run as dilute ethyl alcohol solutions using alcohol as the reference material.

Materials Used. The materials used are listed in Table I.

EXPERIMENTAL DATA ON PLASTICS

Effect of 2H4MB on the Light Stability and Outdoor Exposure of Plasticized PVC Formulations. Incorporating small amounts of organic compounds capable of absorbing harmful ultraviolet radiation to improve the light resistance of plastics has been known for some time (*13,15*); only recently this technique has been utilized successfully in plasticized poly(vinyl chloride). Probably, the primary reason for the delay in the discovery of

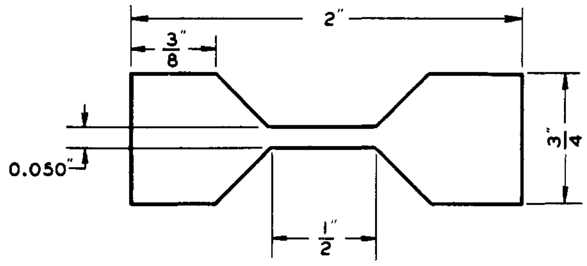


Figure 1. Micro specimen die used to cut samples for mechanical property evaluation during exposure tests

Table I. Materials Used

Chemical Name		Trade Name	Phr
Plasticizers[a]			
Di-2-ethylhexyl phthalate		DOP	
Butyl benzyl phthalate		Santicizer 160	
Diisodecyl phthalate		DIDP	
Stabilizers			
Epoxidized soybean oil[b]	Liquid epoxy-cadmium system 1	Paraplex G-62	3
Cadmium 2-ethylhexoate barium octylphenate, triphenyl phosphite mixture + zinc octoate[c]		Mark M	2
		Mark PL	0.25
Epoxidized soybean oil[b]	Solid epoxy-cadmium system 2	Paraplex G-62	3
Barium-cadmium laurate mixture[c]		Mark XI	2
Triphenyl phosphite[c]		Mark XX	1
Lead stearate[d]		DS-207	
Lead silicate[d]		POS-C	
Lead phosphite[d]		Dyphos	
Dibutyltin dilaurate (DBTDL)[e]		. . .	
Dibutyltin maleate (DBTM)[e]		. . .	
Fillers and Pigments			
Calcium carbonate[f]		Atomite	
Titanium dioxide[g]		Titanox RA	
Titanium dioxide[g]		Titanox RCHT	
Ultraviolet light screening agents (benzophenone)			
2-Hydroxy-4-methoxy (2H4MB)[h]		U. V. Absorber No. 9 Uvinul M-40	
2,4,4'-Trihydroxy[i]		. . .	
2,4-Dihydroxy-4'-methoxy[i]		. . .	
2,4-Dihydroxy[i]		. . .	
2,2'-Dihydroxy[i]		. . .	
2-Hydroxy[i]		. . .	
2-Hydroxy-5-methyl[i]		. . .	
2-Hydroxy-3,5-dichloro[i]		. . .	
4,4'-Dihydroxy[i]		. . .	
4,4'-Dimethoxy[i]		. . .	
4-Hydroxy[i]		. . .	
o-Phenyl[i]		. . .	
Resin			
Poly(vinyl chloride)[a]		Opalon 300	

[a] Monsanto Chemical Co.
[b] Rohm & Haas Chemical Co.
[c] Argus Chemical Co.
[d] National Lead Co.
[e] Metal & Thermit Corp.
[f] Thompson Weinman Corp.
[g] Titanium Pigments Corp.
[h] American Cyanamid Co., Antara Chemicals Division
[i] Monsanto laboratory synthesis

Table II. Relative Reflectances of DOP Formulations with and without 2H4MB after Heat and Light Exposure

Hours Exposed	Control, % Weatherometer Exposure	2H4MB (2 PHR), %
0	50	60
50	30	40
250	24	24
	Minutes at 170° C. Circulating Air Oven Heat Stability	
0	60	60
20	15	10

the usefulness of ultraviolet screening agents in PVC was that these materials apparently do not function alone in the PVC formulations as they do in other resins. The PVC-plasticizer system must first be adequately stabilized against the effects of heat before the screening compound can operate satisfactorily (*7*). To show this experimentally, PVC plasticized with di-2-ethylhexyl phthalate (DOP) specimens were exposed (with and without 2H4MB) in the Weatherometer and to heat. Table II shows that within 50 hours of light exposure and 20 minutes at 170° C., both the samples containing no 2H4MB or those with the 2H4MB alone displayed serious degradation. However, the light stability of films containing specific stabilization systems can be prolonged three- to four-fold by the incorporation of small amounts of 2H4MB.

Light Stability of Plasticized PVC Containing 2H4MB. Epoxy-Cadmium Stabilization System. Prior to the discovery of the effectiveness of light screening agents as stabilizers for PVC, the epoxy-cadmium system was one of the most efficient known for both heat and light. This system has been found to protect clear 40-mil vinyl sheeting for 1000 Weatherometer or Fadeometer hours and for 2 hours at 170° C. without serious discoloration or stiffening. Figures 2 to 5 show clearly the vast improvement in color retention, elongation, tensile strength, and modulus effected by 2H4MB on the epoxy-cadmium system containing 100 parts of Opalon 300, 50 parts of DOP, and the indicated stabilizer.

Plotted in Figure 2 are the exposure time *vs.* relative reflectance curves for a number of formulations containing two examples of commercially available epoxy-cadmium systems with and without 2H4MB. Also included among the curves is an unstabilized control. The two systems containing 2H4MB exhibit remarkable color retention and withstand Weatherometer exposure to the extent of three or four times those containing the epoxy-cadmium system alone. The more recent liquid barium-cadmium system 1 is superior to the solid barium-cadmium system 2 in both cases. The ultimate light stability can be increased from approximately 1000–1500 to 4000–5000 hours by the addition of 2H4MB. Five thousand hours represents approximately 1 year of testing in the artificial weathering units.

Similarly, in Figure 3 is plotted the exposure time *vs.* ultimate elongation. As in the case of the color retention curves, the retention of elongation is vastly superior in the films containing 2H4MB. There also, the liquid system is more efficient than the solid system. Of particular interest is that a sudden drop in elongation occurs just prior to the complete degradation of the specimens as detected by visual color methods, though not in every case. In some instances the elongation drops steadily as the exposure time increases while the color of the specimens remains essentially unchanged. This situation can lead to erroneous conclusions if the degradation is measured by color retention alone. Actually, a given formulation could appear to be visually "stable" but fail in use because of mechanical property loss.

Figures 4 and 5 show the relationship of both tensile strength and modulus at 100% elongation for the same formulations. Again the stabilizing action of 2H4MB is apparent. As expected, the tensile strength decreases while the modulus increases with exposure time.

Lead Stabilization System. One of the first commercial methods of stabilizing PVC was the incorporation of basic lead salts. Although still used today because of special properties, they are less desirable than the epoxy-cadmium components in certain applications. Earlier results by this laboratory have shown that, in general, the best light stability that can be expected from them is about 500 Weatherometer hours, and the best heat stability is 1 hour at 170° C. in a 40-mil plasticized DOP sheet. An exception is the stabilizer dibasic lead phosphite which imparts much better heat and light resistance than the other lead compounds. It has the drawback of rendering the composition opaque, however.

In Figures 6 and 7, PVC with 100 parts of Opalon 300, 25 parts of DOP, 25 parts Santicizer 160 and the indicated common lead stabilization systems, the effect of 2H4MB on color and elongation retention is shown. Obviously, adding 2H4MB to the system lead silicate–lead stearate has very little advantage. Although there is some improvement in initial color and color retention, this particular lead system does not pro-

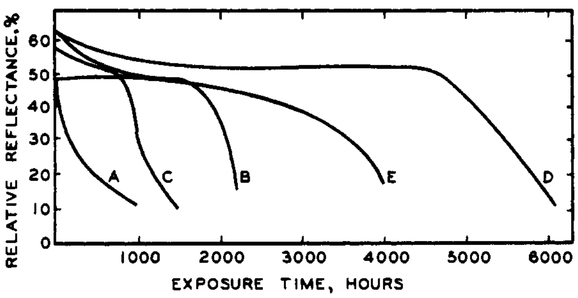


Figure 2. Effect of exposure on color retention

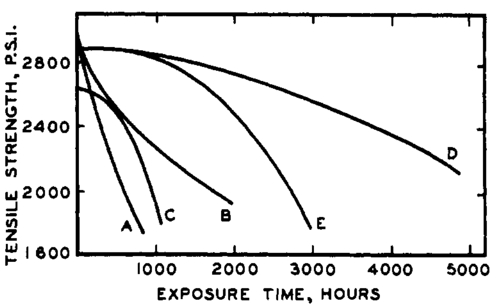


Figure 4. Change in tensile strength during exposure

	Parts
A. No stabilizer	
B. Epoxy-cadmium system 1	
C. Epoxy-cadmium system 2	
D. Epoxy-cadmium system 1-2H4MB	2
E. Epoxy-cadmium system 2-2H4MB	2

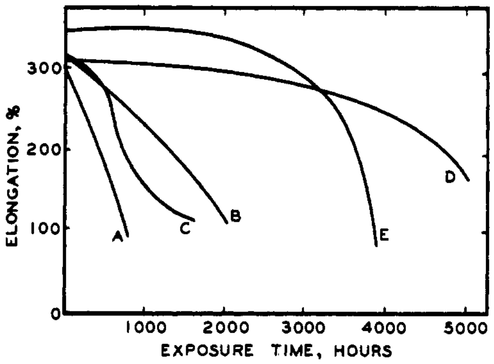


Figure 3. Elongation due to exposure

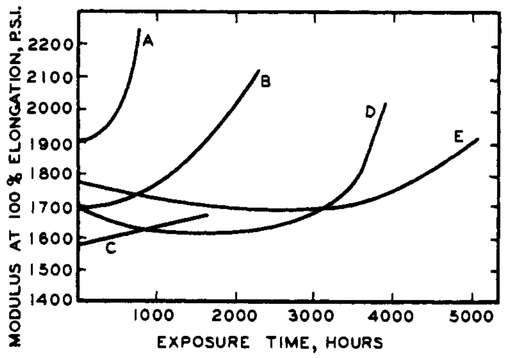


Figure 5. Exposure time *vs.* modulus

vide adequate heat stability which must be present before the screening agent can function properly. Excellent results were obtained with the dibasic lead phosphite–lead stearate mixture. Although opaque, the color stability of this formulation rivals that of the epoxy-cadmium study.

The elongation-exposure time study in Figure 7 also reveals the inferiority of lead silicate–lead stearate and the superiority of dibasic lead phosphite–lead stearate. Unlike the results from the epoxy-cadmium work, the elongation does not fall off so abruptly, but decreases gradually. At certain stages during exposure the sample is not discolored but the elongation is noticeably decreased.

Tin Stabilization System. Also used as stabilizers are some quadrivalent organotin compounds (*11,15*), which provide light stability between the lead and epoxy-cadmium systems. These compounds produce stability to the extent of about 700 Weatherometer hours and about 60 minutes at 170° C. in a DOP sheet. Heat stability can be greatly improved with the organotin mercapto stabilizers, which also do not impair clarity to vinyl stock.

In Figures 8 and 9 the relative reflectance and elongation are plotted against exposure time for two representatives of the tin system. These films contain 100 parts of Opalon 300, 25 parts DOP, 25 parts of Santicizer 160, and the indicated stabilizer. 2H4MB contributes a significant extension to the dibutyltin dilaurate (DBTDL) and dibutyltin maleate (DBTM) mixture (Figure 8). Conversely, it has but a slight effect on the formulations containing the organotin stabilizer (structure unknown). Moreover, the color retention and ultimate elongation of the DBTDL-DBTM formulation is superior to the organotin-2H4MB combination, base system of the type in which the 2H4MB is unsuccessful. The DOP-Santicizer 160 plasticizer system used in this experiment made the control different in this case.

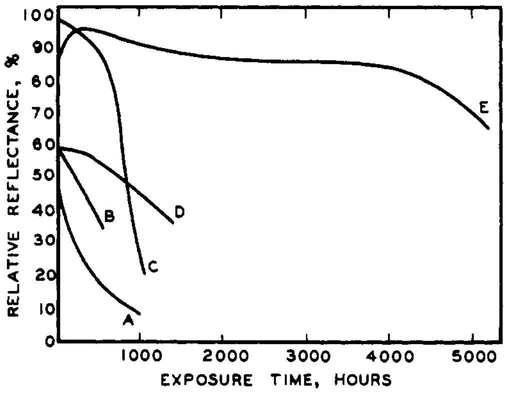


Figure 6. Effect of exposure on color retention

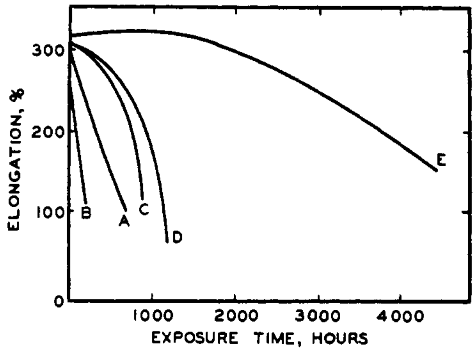


Figure 7. Elongation due to exposure

	Parts
A. No stabilizer	
B. Lead silicate– lead stearate	3 0.5
C. Dibasic lead phosphite lead stearate	3 0.5
D. Lead silicate– lead stearate– 2H4MB	3 0.5 2
E. Dibasic lead phosphite– lead stearate– 2H4MB	3 0.5 2

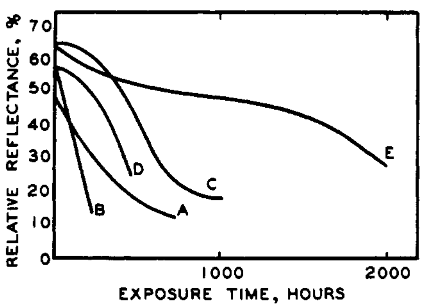


Figure 8. Effect of exposure on color retention

	Parts
A. No stabilizer	
B. Organotin	2
C. DBTDL- DBTM	1.8 0.2
D. Organotin- 2H4MB	2 2
E. DBTDL- DBTM- 2H4MB	1.8 0.2 2

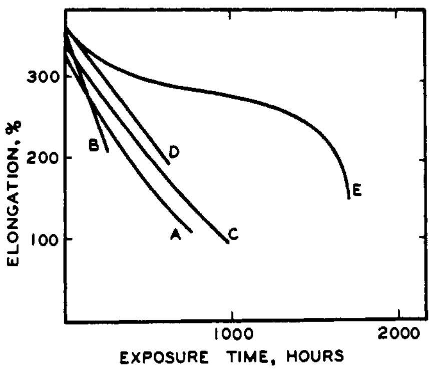


Figure 9. Elongation due to exposure

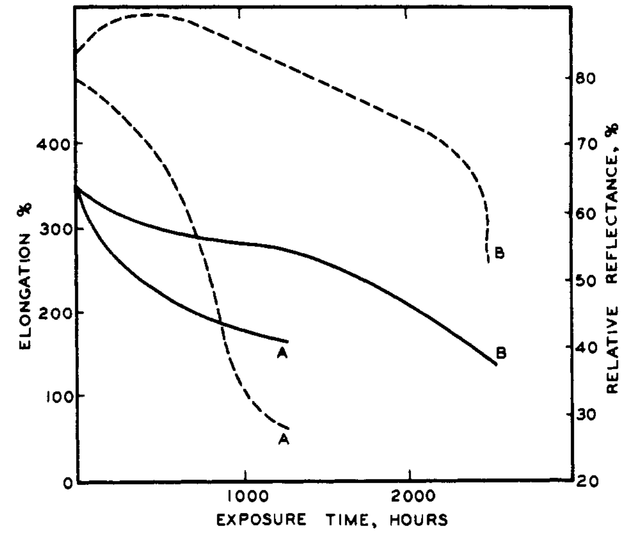


Figure 10. Retention of color and elongation of filled PVC formulations containing 2H4MB

A. Epoxy-codmium system 2

B. Epoxy-cadmium system 2-2H4MB 1 Part

———————— Elongation

- - - - - - - - - - Relative reflectance

Filled Systems Containing 2H4MB. Except in applications where clarity is specified, almost every commercial vinyl composition has an appreciable amount of inert filler and/or pigment. Besides being economical, judicious concentrations of materials such as calcium carbonate, barium sulfate, clay, and other siliceous materials could affect the light stability of the formulation. Generally, because of the opaqueness of the titanium dioxide pigmented compositions much of the harmful radiation is reflected, thereby lessening its deleterious effect. Also, the filler apparently masks a significant amount of the chromophoric decomposition products. In Figure 10, the color and elongation retention of a calcium carbonate-filled system containing 20 parts of Atomite, 100 of Opalon 300, 25 of DOP, 25 of Santicizer 160, and 2H4MB are definitely superior to the same formulation without the screening agent. Figure 11 shows the retention of tensile strength obtained with 2H4MB as opposed to its steady decrease in the absence of this additive in the Opalon 300, DOP, and Santicizer 160 formulation. Despite the reasonable color retention effected by calcium carbonate alone (Figure 10), the tensile strength is continually decreasing in the specimens. This example shows the danger of evaluating light stability on the basis of color alone. The curves of Figures 12 and 13 illustrate the action of 2H4MB on formulations containing calcium carbonate in combination with titanium dioxide, showing the increased stability afforded by the titanium dioxide. The utility of 2H4MB in the filler-pigment combinations (curves *A* and *D*) is confirmed. Titanox RA is superior to Titanox RCHT; the difference can be explained by the hiding powers of the two materials (*16*). The RA material has a relative hiding power of 147 sq. feet per pound, whereas the RCHT is 57 sq. feet per pound. This PVC formulation is 100 parts of Opalon 300, 25 of DOP, 25 of Santicizer 160, 3 of epoxidized soya oil, 2 of barium cadmium laurate, 0.5 of triphenyl phosphite and the remaining constituents as indicated.

Outdoor Exposure of Films Containing 2H4MB. Although it is difficult to demonstrate complete correlation between the accelerated light units and actual outdoor weathering, the remarkable stabilizing efficiency of 2H4MB in protecting plasticized vinyl film against weathering is apparent in both types of exposure (*5*). Compiled in Table III are the changes in tensile strength and elongation of four film formulations with and without 2H4MB. The two films containing the additive continue to resist the effects of exposure, whereas the two without 2H4MB degraded after approximately one summer.

ULTRAVIOLET LIGHT ABSORPTION AND STABILIZATION

The mechanisms involved in the degradation of plasticized poly (vinyl chloride) are complex and have been treated by many investigators (*2, 6, 9*). It is generally concluded that dehydrohalogenation gives rise to a polyene structure which manifests itself as discoloration. Furthermore, oxygen, from either residual polymerization catalyst, or the air, catalyzed by ultraviolet light or heat attacks tertiary carbons in the resin or plasticizer molecules causing the formation of carbonyl groups, momentary loss in molecular weight, and subsequent cross linking. These degradative reactions combined with the steady loss of plasticizer due to water extraction and volatility result in ultimate stiffening and embrittlement of the composition.

The phenomenal light stability afforded by 2H4MB, however, has been attributed to its ability to absorb the catalytic ultraviolet light from the sun without the development of fluorescence or the formation of colored by-products. Because this compound does not function properly as a stabilizer in a

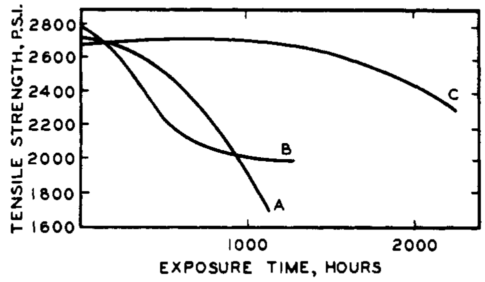


Figure 11. Tests on calcium carbonate-filled systems containing 2H4MB

	Parts
A. No calcium carbonate	
B. Epoxy-cadmium system 2- calcium carbonate	2 20
C. Epoxy-cadmium system- calcium carbonate- 2H4MB	2 20 1

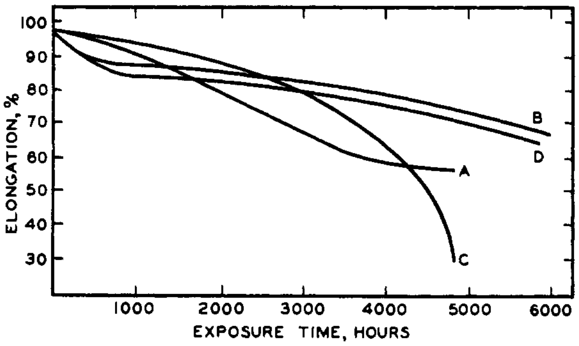


Figure 12. Color retention of filled systems containing 2H4MB

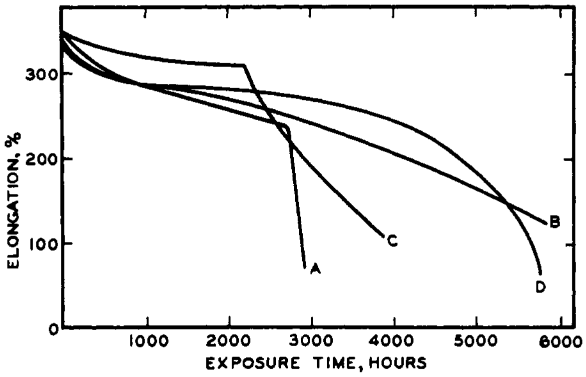


Figure 13. Elongation of filled systems containing 2H4MB

	Parts
A. Titanox RA	**5**
calcium carbonate	**15**
B. Titanox RA	**5**
2H4MB	**1**
C. Titanox RCHT	**5**
2H4MB	**1**
D. Titanox RA	**5**
calcium carbonate	**15**
2H4MB	**1**

vinyl composition unless other stabilizers are present, it lessens the burden of the system, thereby allowing them to be operative over longer periods of time.

Products similar to 2H4MB structure were evaluated for their light-screening action in PVC. In conjunction with Weatherometer tests, ultraviolet absorption studies were made of the benzophenone derivatives listed in Table IV to determine whether a correlation exists between the ultraviolet absorption spectrum of a potential light screening agent per se, and its Weatherometer stability. The results should indicate whether valid predictions could be made for the ultraviolet screening ability of a formulated compound merely from an examination of its ultraviolet absorption spectrum. The latter would be valuable for screening new compounds prior to full scale testing programs.

Table III. Outdoor Exposure Data

	Formulations			
	1	2	3	4
Opalon 300	100	100	100	100
DOP	50	50	...	...
DIDP	...	...	50	50
Paraplex G-62	3	3	3	3
Liquid Ba/Cd + triphenyl phosphite	2	2	...	...
Ba/Cd laurate	...	...	2	2
Zinc octoate + triphenyl phosphite	0.25	0.25	...	...
Triphenyl phosphite	...	...	0.50	0.50
Stearic acid	0.25	0.25	0.25	0.25
2H4MB	...	1	...	1

Results

	1		2		3		4	
	T.S., p.s.i.	Elong., %	T.S., p.s.i.	Elong., %	T.S., p.s.i.	Elong., %	T.S., p.s.i.	Elong., %
Prepared specimens								
June 1956	3290	355	3210	390	3200	360	3125	330
Aug. 1956	3170	355	3200	374	3100	350	3200	330
Nov. 1956	3375	354	3400	370	2750	300	3215	335
July 1957	2370	210	3500	365	2020	140	3140	300
Nov. 1957	Complete failure		3250	350	Complete failure		3050	295

Table IV. Ultraviolet Light Absorption and Weatherometer Stability

Benzophenone derivative	85% Ultraviolet Cutoff, μ	Weatherometer Stability
2,4,4'-Trihydroxy	363	Good
2,4-Dihydroxy-4'-methoxy	362	Good
2,4-Dihydroxy	359	Good
2-Hydroxy-4-methoxy	356	Good
2,2'-Dihydroxy	362	Good
2-Hydroxy	358 (290-311)	Fair
2-Hydroxy-5-methyl	370 (290-326)	Fair
2-Hydroxy-3,5-dichloro	358 (293-346)	Fair
4,4'-Dihydroxy	325	Poor
4,4'-Dimethoxy	334	Poor
4-Hydroxy	326	Poor
o-Phenyl	297	Poor

The ultraviolet absorption spectra were obtained for dilute ethyl alcohol solutions of the benzophenone derivatives, and the data are plotted in Figures 14 to 16 as absorbance (α) *vs.* wave length. α is obtained from the relationship log (I_0/I) =

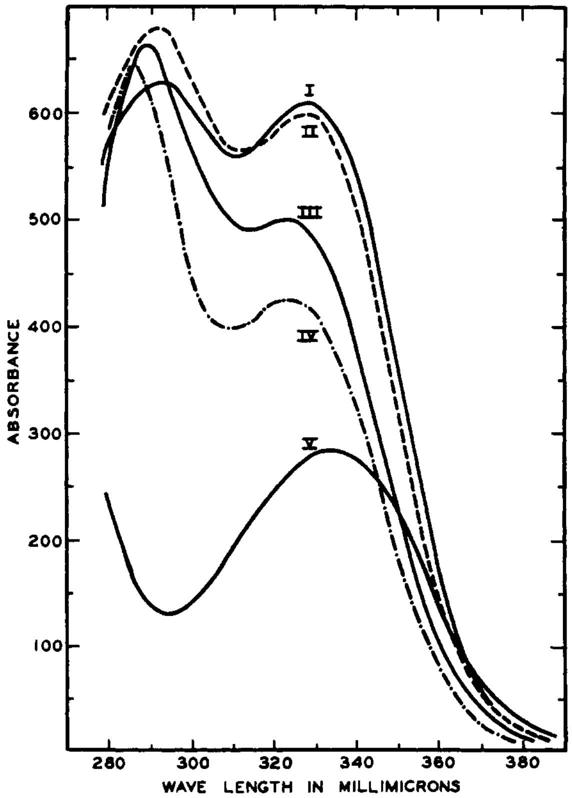


Figure 14. Good Weatherometer stability

I. 2,4,4'-Trihydroxybenzophenone
II. 2,4-Dihydroxy-4'-methoxybenzophenone
III. 2,4-Dihydroxybenzophenone
IV. 2-Hydroxy-4-methoxybenzophenone
V. 2,2'-Dihydroxybenzophenone

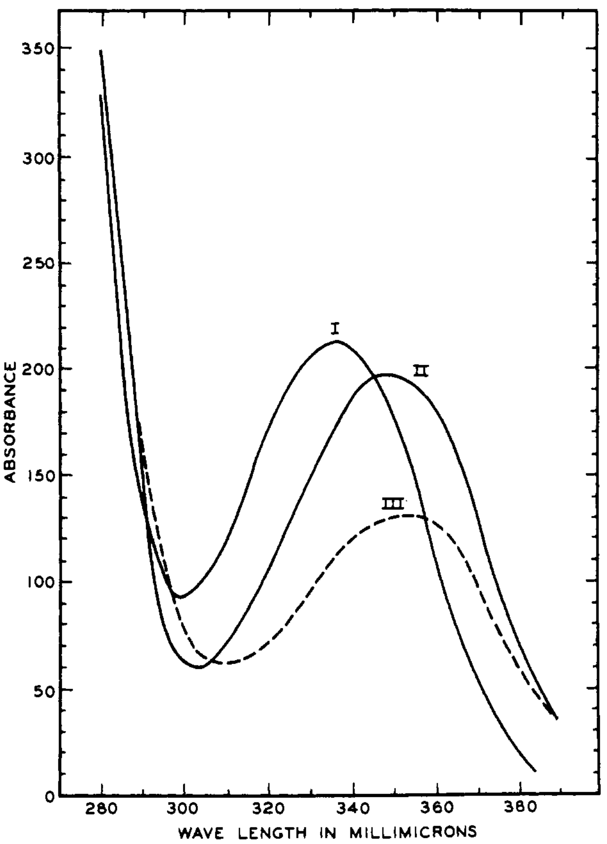


Figure 15. Fair Weatherometer stability

I. 2-Hydroxybenzophenone
II. 2-Hydroxy-5-methylbenzophenone
III. 2-Hydroxy-3,5-dichlorobenzophenone

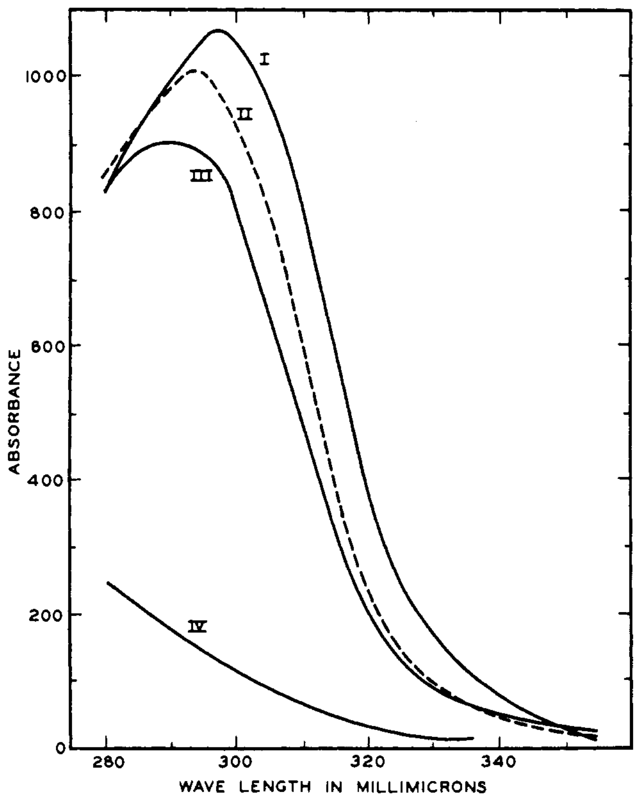


Figure 16. Poor Weatherometer stability

I. 4,4′-Dihydroxybenzophenone
II. 4,4′-Dimethoxybenzophenone
III. 4-Hydroxybenzophenone
IV. o-Phenylbenzophenone

αCl = absorbance, where C is the concentration in grams per 100 ml. solution and l is the thickness of the absorbing sample in centimeters.

Since the earth's atmosphere cuts off all radiation of wave lengths lower than about 290 μ, it is evident that in order to act as an ultraviolet screening agent, a compound should absorb strongly in the region of 290 to 400 μ. To assist in evaluating the ultraviolet light screening action of the materials studied, the ultraviolet absorption spectrum for each compound has been calculated for a standard set of conditions—namely, a film 0.004 inch thick formulated with 100 parts of PVC, 50 parts of plasticizer, 6 parts of epoxy-cadmium mixture, and 1 part of ultraviolet screening agent. It is assumed that all the ingredients in the formulation except the screening agent are transparent in the 290 to 400 μ region. These spectra are shown in Figures 17 to 19. Table IV shows the 85% ultraviolet cutoff point calculated for each compound under the standard conditions and its Weatherometer stability. This cutoff is an arbitrarily chosen point representing that wave length above which less than 85% of the ultraviolet radiation is absorbed.

In the benzophenone series studies, a correlation exists between the ultraviolet absorption spectrum of a potential light screening agent per se with its Weatherometer performance. The formulated compounds that have 85% ultraviolet cutoffs in the region of 350 to 370 μ gave fair to good Weatherometer stability. The compounds that had poor Weatherometer stability (4,4′-dihydroxy-, 4,4′-dimethoxy-, 4-hydroxy-, and

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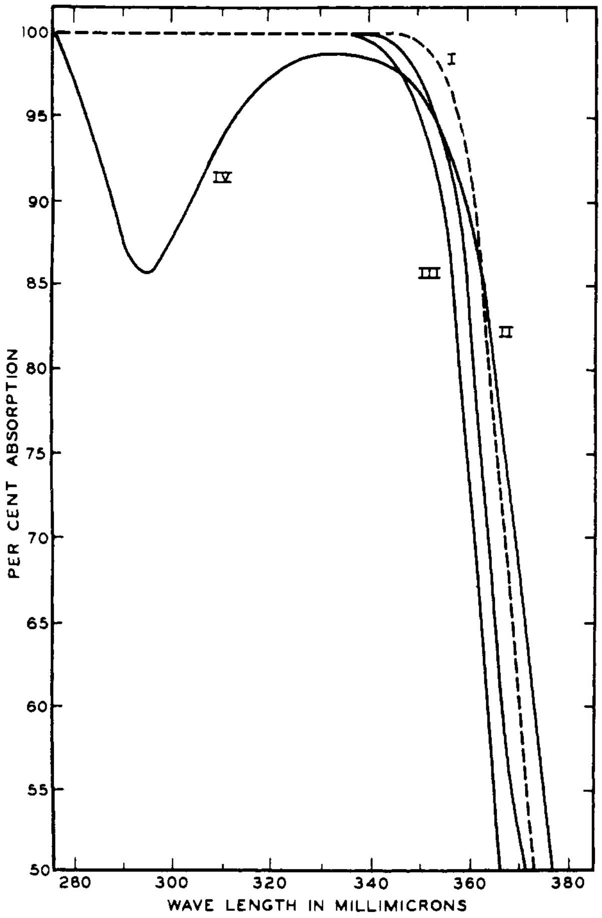

Figure 17. Good Weatherometer stability

I. 2,4,4′-Trihydroxy- and 2,4-dihydroxy-4′-methoxybenzophenone
II. 2,4-Dihydroxybenzophenone
III. 2-Hydroxy-4-methoxybenzophenone
IV. 2,2′-Dihydroxybenzophenone

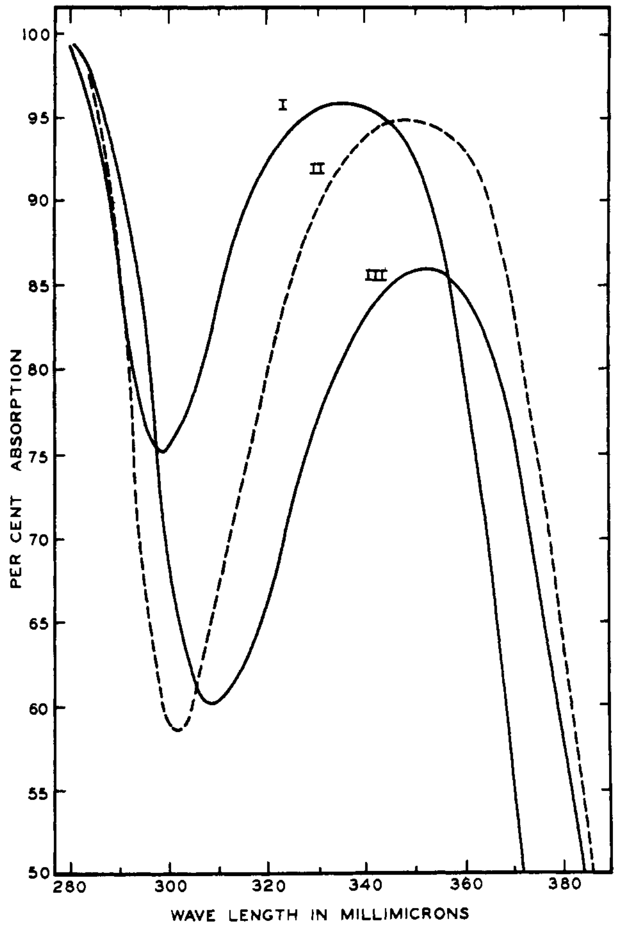

Figure 18. Fair Weatherometer stability

I. 2-Hydroxybenzophenone
II. 2-Hydroxy-5-methylbenzophenone
III. 2-Hydroxy-3,5-dichlorobenzophenone

o-phenylbenzophenone) had 85% ultraviolet cutoffs displaced toward the shorter wave length region of 300 to 330 μ. The distinguishing feature in correlating good and fair Weatherometer stability with the ultraviolet absorption data is the absorption minima exhibited by the fair compounds (2-hydroxy-, 2-hydroxy-5-methyl-, and 2-hydroxy-3,5-dichlorobenzophenone) in the region of 290 to 340 μ. In this region the ultraviolet absorption falls to 60 to 75%.

If the assumption of the 85% ultraviolet cutoff point is a valid indication of light-screening ability, then apparently two photochemical mechanisms are involved in formulated PVC degradations. High light absorbtivities in the region of 340 to 370 μ appear to be favorable for good and fair Weatherometer stability. The compounds that absorbed less than 85% of the radiation in this region (4,4'-dihydroxy-, 4,4'-dimethoxy-, 4-hydroxy-, and *o*-phenylbenzophenone) gave poor Weatherometer stability. A secondary, and apparently slower, mechanism appears to be activated by ultraviolet radiation in the region of 290 to 340 μ. The compounds that gave fair Weatherometer stability (2-hydroxy-, 2-hydroxy-5-methyl-, and 2-hydroxy-3,5-dichlorobenzophenone) show an adsorption minimum with less than 85% adsorption in this region.

In the benzophenone series valid predictions could be made of the ultraviolet screening ability of a compound by calculating its absorption spectrum under standard conditions. The only anomaly in the series is the results obtained for 2,2'-dihydroxybenzophenone, which exhibits the same absorption minimum used to differentiate good and fair compounds, although not as intense as the fair materials. This correlation applies only to light screening action of these agents and does not take into account possible chemical activity that might contribute to stability.

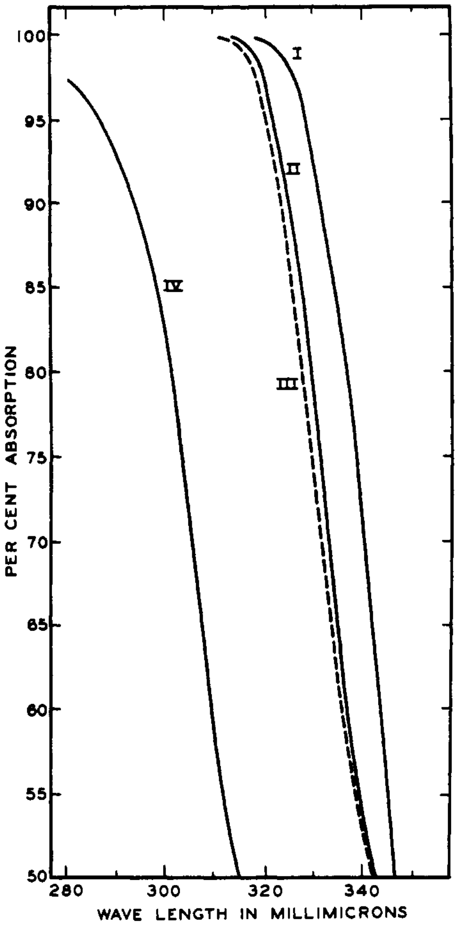

Figure 19. Poor Weatherometer stability

I. 4,4'-Dihydroxybenzophenone
II. 4,4-Dimethoxybenzophenone
III. 4-Hydroxybenzophenone
IV. o-Phenylbenzophenone

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