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Soil Burial Tests:

Effect of Soil Burial Exposure on the Properties of Plastics for Wire and Cable

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This paper describes the studies that have been made on polyethylene and vinyl chloride plastic wire and cable coatings after up to eight years soil burial at sites in Georgia and New Mexico. The initial samples of both types of plastics were exposed in the form of extruded wire while the more recent studies on vinyl plastics have been made on molded sheet. The polyethylenes were observed to have excellent resistance to deterioration, but certain of them may be susceptible to adverse changes in physical properties that appear to be associated with polymer crystallization. The vinyl plastics vary in their resistance to deterioration, depending primarily upon the choice of plasticization. Compositions of both types of plastics can be prepared that may be expected to provide satisfactory long-term service as wire or cable coatings in a soil environment.

I. INTRODUCTION

A soil burial study was undertaken on polyethylene and vinyl chloride plastics in order to develop a background of knowledge concerning these materials that would be useful in the design of buried wire and cable. These plastics were selected for study because of their wide acceptance as coatings on communications wire and cable and because their chemical structure suggested that they might be expected to possess good resistance to soil burial.

In the initial phase of this program, wires with extruded plastic coatings on copper and aluminum conductors were buried at the Georgia and New Mexico test sites. Half of the samples were exposed with a 48-volt positive dc potential on the conductors and half without it. An interim report on the vinyl plastics in these tests was made at the end of four years of soil burial.[1] The observations at that time indicated that the nature of the conductor, potential, and variations in the depth of burial (within the limits studied) were not critical variables. On the basis of these observations, it was decided, henceforth, to examine only coatings on copper conductor without potential from a mean depth.

In the second phase of this program, molded sheet samples of vinyl plastics were buried mounted on polyethylene tubes. These were introduced because they permitted the preparation of samples from small roller mill mixed lots which facilitated the study of compositional variables. The objectives of this work have been to study the performance of a number of new plasticizers and to confirm certain earlier observations made on wire samples.

The information compiled thus far has been of assistance in understanding the mechanisms involved in the changes that may occur in plastics on soil burial and is serving as a valuable guide in selecting the most permanent types of coatings for use on buried structures.

II. CHEMISTRY OF PLASTICS FOR WIRE AND CABLE

The polyethylene plastics buried as extruded wire coatings were chosen from available commercial compositions (see Table I). The resins from which these plastics were manufactured were of both low- and high-density types (0.92 to 0.96) with subdivisions of low and high molecular weight grades (melt indices 2.0 to 0.3). The low-density resins used in this study are similar to grades commonly used today, but the high-density resins were first generation low-pressure grades that are now only of academic interest since they suffered from thermal embrittlement[2] and have been superseded by reportedly improved grades.

Ordinarily, polyethylenes inherently possess suitable mechanical and electrical properties and are modified with only minor percentages of additives to aid stabilization in processing and service or to modify superficial properties. Among the additives investigated were antioxidants, carbon black, and butyl rubber. Also buried were coatings crosslinked by electron beam irradiation as well as a coating foamed with azodicarbonamide.

The vinyl plastics buried as wire coatings ranged from semirigid to highly flexible grades and consisted of both commercial and experimental formulations. The compositions were based on high molecular

TABLE I—COMPOSITION OF POLYETHYLENE PLASTIC WIRE COATINGS USED IN SOIL BURIAL TESTS

Compound No. −57	Polyethylene Wire Coating			
	Base Polymer		Modification	
	Density	Melt Index[‡]	Antioxidant	Other Additives and/or Treatment
450	0.92	2.0	—	—
464, 468	0.92	2.0	0.1% Thiocresol[*]	—
456	0.92	1.1	0.1% Thiocresol[*]	—
451, 481[§]	0.92	0.3	0.1% Thiocresol[*]	—
455, 472[§]	0.92	0.3	0.1% Thiocresol[*]	2.7% Medium Channel Carbon Black
453	0.92	0.3	0.1% Thiocresol[*]	5% Butyl Rubber (IIR)
470	0.92	0.3	0.1% Thiocresol[*]	25% Butyl Rubber (IIR); plus 3% Medium Channel Carbon Black
460	0.92	0.3	0.1% Thiocresol[*]	Irradiated with Crosslinking Agent
466	0.92	0.3	0.1% Thiocresol[*]	Irradiated with Crosslinking Agent; plus 2.7% Medium Channel Carbon Black
452	0.92	2.0	0.07% Aryl Diamine[**]	Foamed with Azodicarbonamide
454, 457[§]	0.95	—	—	—
458	0.96	0.5	0.01% Tertbutyl Phenol[†]	—
483	0.95	—	—	Irradiated with Crosslinking Agent
475	Polypropylene, Natural			

[*] 4,4′ Thiobis (6-tertbutyl m-cresol)
[**] N, N′ Diphenyl-p-phenylene diamine
[†] 2,6 Di-tertbutyl-4-methyl phenol
[‡] ASTM Method D1238, Condition E (190°C, 216g load)
[§] Compounds obtained from different manufacturing sources

weight homopolymer suspension resins conforming approximately to a GP6-grade per ASTM D1755,[3] with the exception of coating No. 403, which was based on a 5-percent acetate copolymer. To obtain the desired processing and ultimate properties in a vinyl plastic, it is necessary to incorporate with the resin plasticizers, fillers, colorants, stabilizers, and lubricants totaling, sometimes, as much as 50 percent by weight of the plastic. The various ingredients are thermoplastically mixed with the resin to obtain a homogeneous plastic. To accomplish the mixing, a roller mill, banbury, screw plasticator, or one or more of these in combination, are ordinarily used.

The plasticizer content of the vinyl wire coatings is given in Figs. 5 and 6. Wherever octyl ester plasticizers are referred to, the ester intended is that of 2-ethylhexanol. Details regarding other ingredients in these coatings are a matter of record.[1]

The vinyl compounds used in the second phase of the investigation employing molded sheet samples were all experimentally prepared. They were formulated with a number of new plasticizers, as well as some previously used in the wire coatings, and they included a series of compounds to examine the effect of various inorganic fillers at rather high loading (see Tables IV and V). Among the new plasticizers examined were two trimellitates, a chlorinated hydrocarbon, a chlorinated polyethylene, and a chlorophenyl diphenyl phosphate. The chlorinated hydrocarbon was a liquid having 52 percent chlorine on an essentially normal C_{15} fraction. The chlorinated polyethylene was a solid amorphous polymer of 40 percent chlorination based on a linear medium-high molecular weight polyethylene. The purpose of re-examining pentaerythritol plasticizers was to obtain confirmation regarding conclusions reached from the earlier wire studies relative to the merits of monomeric and dimer esters. The polyesters were obtained from several commercial sources and have, according to trade information, a molecular weight range from 1000 to 5000. The polyesters in compositions No. 118-67 and No. 121-67 (see Table IV) differ from the others in that they contain phthalic groups.

III. SAMPLE PREPARATION AND BURIAL

Wire samples of the various plastics were extruded with coatings having a 0.030-inch-thick wall on 22 AWG conductors of copper and aluminum. Lengths of 37.5 feet were buried in the form of an open helix 12 inches in diameter to a maximum depth of 28 inches. For the two- and four-year inspections, two samples of each type of conductor were dug up, one with potential and one without. At the eight-year inspection, only two samples on copper without potential were removed. All samples were returned to the Murray Hill laboratory for evaluation.

Sheet samples were molded to a thickness of 0.030 inch from the various experimental vinyls. From these 1.5 × 3.0-inch rectangular pieces were cut and then mounted on the polyethylene tubes in the conventional manner for exposure below the surface. At inspections, two tubes representing each plastic are removed for evaluation.

IV. EVALUATION METHODS

The wire samples from soil burial were evaluated first for electrical properties using a test length of 30 feet. This was subsequently cut into topsoil and subsoil sections (from average depths of 10 and 24 inches) for tensile tests on the coating after the conductor was removed. Where tensile tests were made on coatings from a mean depth, sections that had been buried at an average depth of 16 inches were used. Lengths of wire adjacent to those taken for tensile tests were visually examined for insect attack, discoloration, and corrosion of the conductors. Sheet vinyl samples, taken from polyethylene supporting tubes after soil burial, were die punched to obtain tensile specimens for evaluation.

Electrical measurements were made using conventional ac (1 kHz) and dc bridge techniques on wire samples immersed in tap water at 23°C. Tensile tests on wire coatings and sheet specimens were performed in accordance with ASTM methods D470 and D412, respectively.[3] In order to economize on material, micro-tensile specimens (see Figs. 7 and 8) were used in performing D412 instead of the larger one specified. The tensile stress at 100-percent elongation, or S-100 modulus, is a particularly useful parameter for following changes in vinyl plastics as it is sensitive to small differences in plasticizer concentration and is not subject to minor imperfections in the manner of a fracture parameter.

The analysis of vinyl sheets for plasticizer retention was made by means of an ethyl ether extraction per ASTM D2124. Where polyester plasticizers were known to be present, an additional four-hour extraction was preformed with a mixture of carbon tetrachloride and methanol, 2:1 by volume.

Infrared analysis was used to determine changes that may have occurred in the chemical structure of the polyethylenes as a result of soil burial. Specimens for scanning were remolded between polished chrome-plated steel plates to 0.010-inch-thick films. Discs about 2 inches in diameter were obtained and scanned in a Perkin-Elmer spectrophotometer, Model 521.

V. POLYETHYLENES—RESULTS AND DISCUSSION

5.1 *Results*

The various polyethylene wire coatings remained generally intact after soil burial and were almost devoid of any noticeable color change. Minor isolated attacks by insects were observed on about half of the samples. These took the form of short chewed areas that did not penetrate to the conductor (see Fig. 1). The polyethylenes showed little or no tendency to react with the metallic conductors. Tarnish was

Fig. 1—Polyethylene coated wire samples after six years soil burial. Upper spools (left to right, Nos. 456, 455, and 450) are from Georgia. Lower spool (No. 456) is from New Mexico and shows insect attack, a section of which is magnified in the insert.

common on the copper conductors but only three cases of spotty green corrosion were detected (Nos. 452, 483, and 450).

The polyethylenes varied in their retention of tensile properties, depending upon the density of the resins from which they were prepared. Those based on low-density resins showed a relatively small change in tensile properties after up to eight years soil burial (see Tables II and III and Fig. 2). With few exceptions, there is a slight increase in tensile strength and yield with some loss in elongation in these coatings. Variations in the molecular weight, as characterized by melt index, do not appear to have an appreciable effect on the retention of tensile properties nor did the addition of carbon black. The only compound tested without antioxidant (No 450) showed a somewhat greater loss in elongation than was common among those in which it was used. The polyethylene plastics based on high-density resins, in contrast, suffered major losses in elongation, in some cases to the point of embrittlement, and decreased somewhat in strength. Polyethylene wire coatings shelf-aged for eight years at room temperature show essentially the same results as those obtained on the polyethylenes after soil burial.

Among the low-density coatings there were also instances where a significant loss in elongation was noted. These occurred where 25 percent butyl rubber had been added (No. 470) and in two of the coatings crosslinked by irradiation. The natural irradiated coating (No. 460) on aluminum lost most of its elongation after four years burial in Georgia (Fig. 2) while the black irradiated coating (No. 466) on copper did likewise after eight years shelf aging. It is interesting to note that G. H. Bebbington, in his paper in this series on rubber-like materials, also reports observing a loss in mechanical properties for a peroxide crosslinked polyethylene without channel black.

The principal change in electrical properties after soil burial occurred in ac breakdown strength where a sizable loss was observed for both high- and low-density types (see Fig. 3). No essential change was noted in the capability of the majority of the coatings to maintain a high dc insulation resistance equal to or greater than 6×10^4 M$\Omega/10^3$ ft. Capacitance measurements on the conductors showed, in general, a slight decrease after soil burial. Notable exceptions in this regard were the foam sample, No. 452, and the high-density sample, No. 483, which increased in capacitance.

A number of low-density coatings were examined for chemical change by comparing the spectra of soil burial and shelf-aged samples.[4] The spectra from most of the buried samples examined (Nos. 451, 453, 456,

TABLE II—ORIGINAL TENSILE AND ELECTRICAL PROPERTIES OF ETHYLENE PLASTIC WIRE COATINGS (AVERAGE OF SAMPLES ON BOTH COPPER AND ALUMINUM)

	Tensile Properties			Electrical Properties (on wire)		
Plastic No. −57	Tensile St. psi	Yield psi	Ultimate Elongation %	Capacitance, 1 kHz pF/ft	AC Breakdown kV	Insulation Proof Test 6×10^4 MΩ/10^3 ft
450	1910	1280	520	32.1	22.0	OK
464	1930	1350	480	31.2	26.0	OK
468	1910	1440	495	33.9	25.0	OK
456	2430	1610	549	30.9	27.5	OK
472	2170	1790	535	36.9	31.5	OK
451	2410	1510	480	32.6	27.0	OK
455	2580	1270	520	37.0	23.5	OK
481	1890	1280	435	33.1	21.5	OK
453	2100	1200	495	32.4	22.0	OK
470	1470	990	485	38.8	29.5	OK
460	1990	1340	370	33.4	22.0	OK
466	1960	1450	340	33.0	22.0	OK
452	620	520	360	21.7	10.5	NG
454	2130	2140	575	33.2	30.5	OK
457	2600	2380	578	32.9	34.5	OK
458	3220	3370	775	32.9	34.5	OK
483	2630	2800	780	30.5	27.0	OK
475	3570	3580	563	32.2	27.5	OK

TABLE III—CHANGE IN TENSILE PROPERTIES OF POLYETHYLENE WIRE COATINGS AFTER 8 YEARS SOIL BURIAL IN NEW MEXICO AND AFTER SHELF AGING*

		Tensile Strength			Yield			Elongation		
		Percent Change			Percent Change			Percent Change		
		8 Yrs Shelf Aging		8 Yrs N.M.†	8 Yrs Shelf Aging		8 Yrs N.M.†	8 Yrs Shelf Aging		8 Yrs N.M.†
Plastic No. −57		Cu	Al	Cu	Cu	Al	Cu	Cu	Al	Cu
Low density, low mol wt	450	−7.9	+29.2	−7.7	+1.9	+12.2	−3.3	−30.0	+11.2	−17.3
	464	+12.1	+21.8	+28.0	0.0	+16.7	−4.9	+5.3	+2.0	+35.5
	468	+17.5	−5.7	+22.7	+5.9	+5.9	−1.0	−6.1	−9.0	+27.1
	456	−3.6	+50.9	−4.5	+3.7	+7.5	−1.1	−16.1	+28.7	+7.7
Low density, high mol wt	451	−9.7	+25.8	+3.1	+1.0	+4.0	−3.3	−18.6	+4.4	−7.8
	481	+53.1	+50.0	+41.0	−2.7	+4.7	−6.4	+18.5	+26.8	+26.1
	455	+4.8	+15.2	−5.0	+12.6	+14.5	−0.2	−8.3	−1.0	−0.6
	472	+27.2	+38.2	+23.3	+4.0	+5.1	−0.1	−0.9	+2.8	+10.2
	453	−1.7	+44.1	−13.7	+12.9	+12.4	+5.0	−11.0	+25.0	−9.8
	470	−1.7	−5.1	−7.6	+0.5	+8.9	−1.1	−3.7	−17.3	−9.4
	460	—	+16.0	+20.1	—	+11.1	+4.6	—	+27.0	+5.4
	466	+26.0	—	+16.6	+68.0	—	+6.1	−97.1	—	+9.7
Foam	452	−2.2	+4.4	+0.6	+4.5	+13.4	+6.1	−15.3	+29.2	−19.7
MEDIAN, % CHANGE		+1.5	+23.8	+3.1	+3.9	+10.0	−1.0	−9.7	+7.8	+5.4
High density	454	−1.7	+0.8	−9.7	−6.9	−16.6	−1.9	−1.9	−20.6	−0.6
	457	+33.9	−14.7	−10.6	+66.7	+7.7	−90.5	<−98.1	<−98.4	−96.0
	458	−24.1	−12.1	−27.6	−19.0	−19.9	+1.4	<−98.7	<−98.7	−97.7
	483	—	−11.6	+2.6	—	—	+14.5	—	—	−97.6
Polypropylene	475	−9.7	+10.3	−8.6	−10.5	−5.4	+5.6	+59.8	−15.9	+70.0

* Shelf aging was conducted in the dark at average indoor room conditions

† Mean depth (avg 16 inches) data

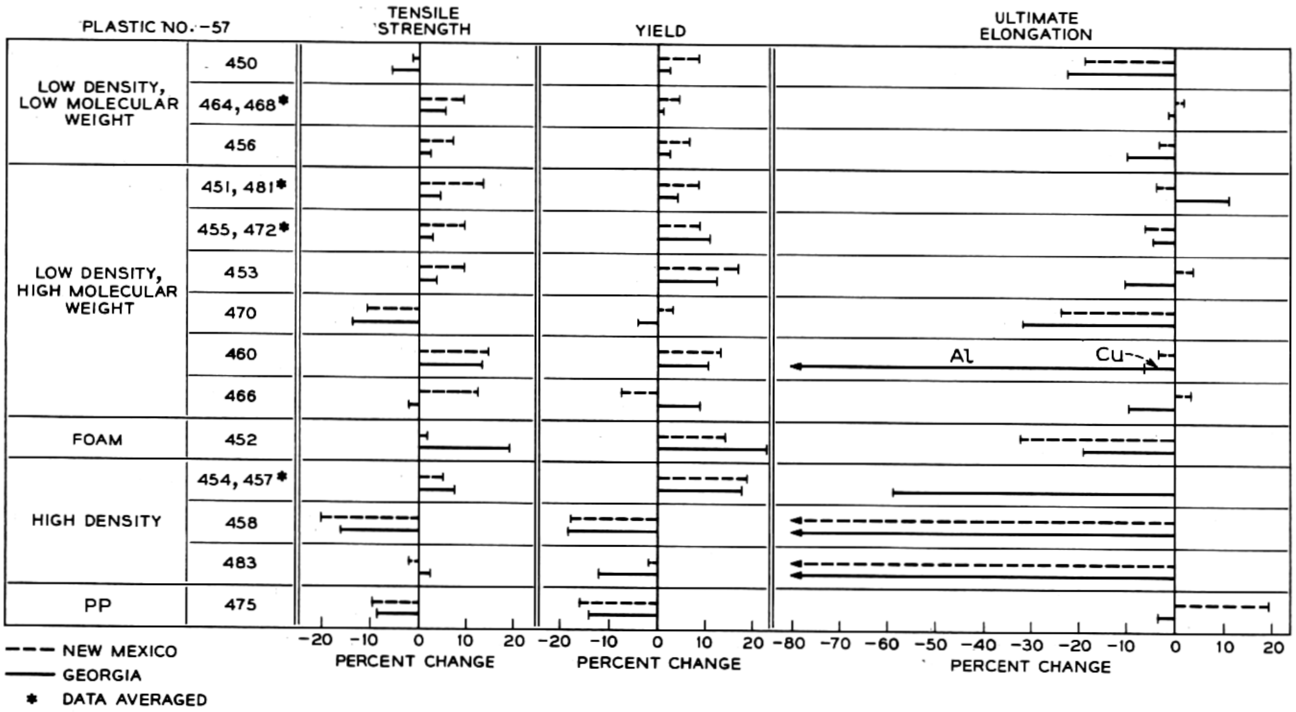

Fig. 2—Change in tensile properties of polyethylene plastic wire coatings after four years soil burial; average values for samples with and without potential on both Cu and Al conductors.

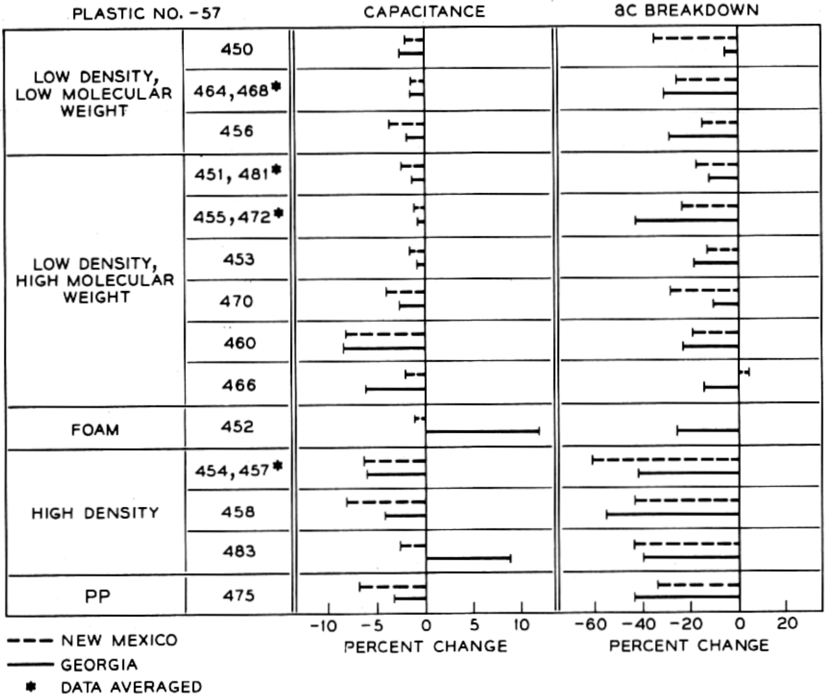

Fig. 3—Change in electrical properties of polyethylene plastic wire coatings after four years soil burial; average values for samples with and without potential on both Cu and Al conductors.

and 464) were found to be identical with the shelf-aged controls except for the appearance of a weak carbonyl band in the 1705 cm^{-1} region. The plastic showing the most noticeable carbonyl absorption (No. 450) contained a natural resin without antioxidant (see Fig. 4). The one high-density coating examined (No. 454) had no detectable carbonyl after either kind of aging.

5.2 *Discussion*

The good soil burial resistance observed for the low-density polyethylenes is consistent with results reported in the literature on these materials. Tensile tests on polyethylene cable coatings buried in inoculated and sterile soil were found[5] to be immune to deterioration. Excellent retention of tensile and other physical properties has been observed for 10-mil polyethylene sheet after seven years accelerated laboratory soil burial tests and after four years field burial service

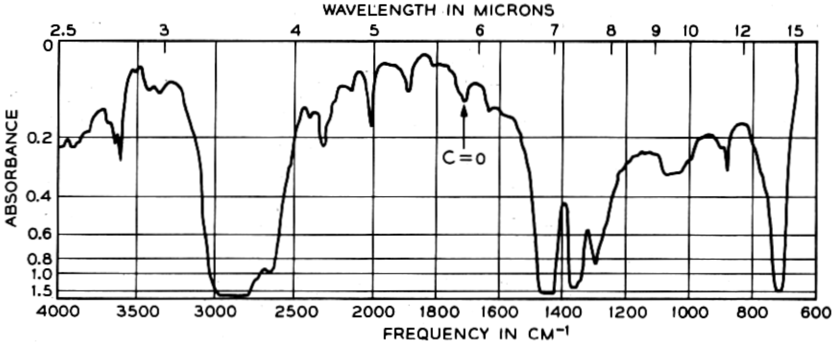

Fig. 4—Infrared spectrum of natural low-density polyethylene (No. 450) showing carbonyl absorption after four years soil burial in Georgia.

in New Mexico.[6] Although no differences of any consequence were noted in our studies among the low-density resins with respect to molecular weight, evidence of biological attack by bacteria has been reported in studies involving exceptionally low molecular weight grades of polyethylene ordinarily not used on wire and cable.[7]

There is some question as to whether the severe loss in elongation observed in the high-density coatings is attributable to the soil environment. Since essentially the same changes occurred in samples retained at room conditions, which are too mild to expect oxidative effects, we are probably dealing with a time-temperature phenomena recognized to occur in these polymers and referred to as thermal embrittlement.[2,8] This embrittlement has also been observed in cable jacketing of these high-density polymers following extended ocean exposure.[9]

The infrared spectra obtained on polyethylenes indicated that they were, with few exceptions, essentially free of chemical decomposition as a result of soil burial or shelf aging. The slight increases detected in the carbonyl content of the low-density coatings may be attributable to either oxidation or possibly to the absorption by the resins of foreign substances. An argument favoring the oxidation is found in the No. 450 coating, which contained no antioxidant and had the most intense carbonyl band. However, since the resin used was a high-pressure branched type polymer with a broad molecular weight distribution, it could also be argued that it might be expected to be fairly absorptive, hence the source of the carbonyl cannot be pinpointed.

The good retention of dielectric and insulation resistance properties are what would have been predicted from the chemical stability exhibited by the polyethylenes. The decrease in ac breakdown strength is probably related to highly localized damage to the coatings sustained during burial or excavation, or from insect attack.

VI. VINYLS—RESULTS AND DISCUSSION

6.1 *Results*

6.1.1 *Wire Coatings*

The vinyl chloride plastics differ from the polyethylenes in that they show some discoloration after soil burial and undergo compositional changes that alter their properties. The appearance of the coatings after eight years burial has not particularly changed since the earlier four-year inspection. Mottling was common with yellow or purple spots appearing frequently, although brown, gray, and pink were also noted. Isolated attacks on the coatings by insects occurred while the condition of the conductors was about the same as that observed for the polyethylenes.

A general aging pattern appears to have developed for most of the vinyl wire coatings (see Figs. 5 and 6). Following an early rapid increase in S-100 modulus, they level off or, at most, continue to increase at

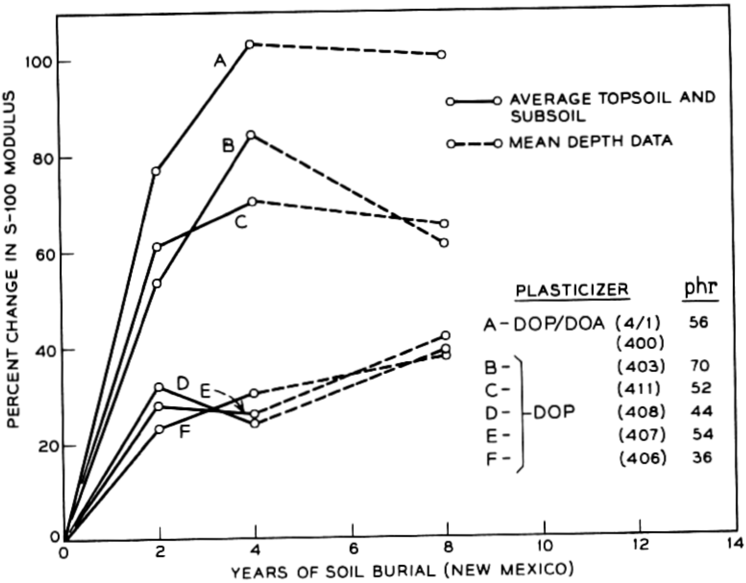

Fig. 5—Effect of soil burial with time on the modulus of vinyl wire coatings containing dioctyl phthalate at various concentrations.

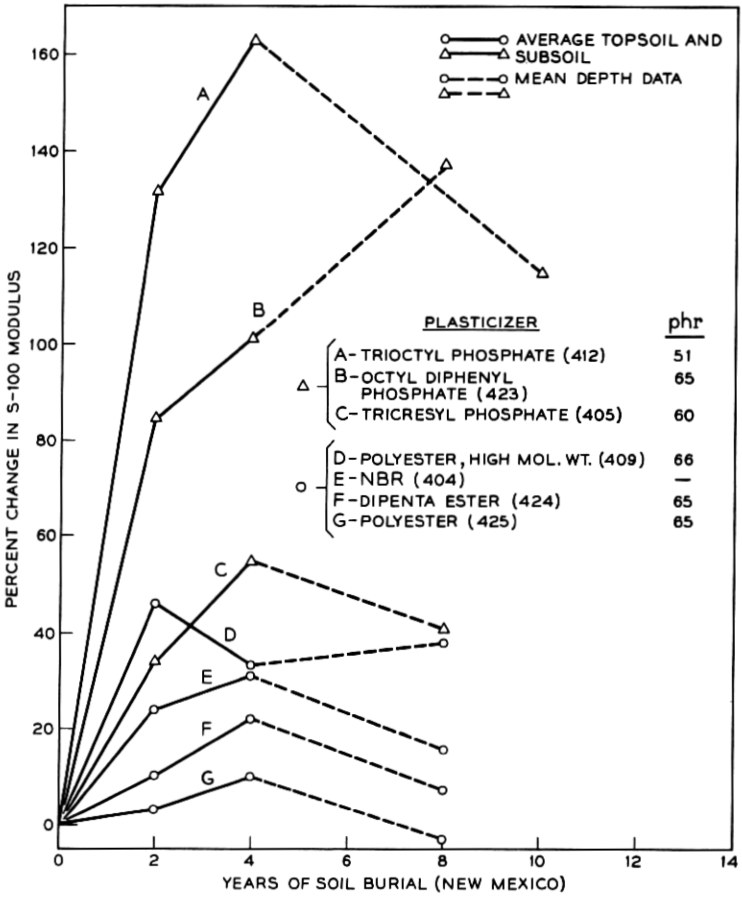

Fig. 6—Effect of soil burial with time on the modulus of vinyl wire coatings varying in plasticization.

a slow rate. A number of coatings formulated with dioctyl phthalates are in this category as well as those prepared with polyesters, nitrile rubber, and tricresyl phosphate. Exceptions are found in the curves for coatings containing octyl diphenyl phosphate (No. 423) which continued to rise sharply and that containing trioctyl phosphate which declined.

6.1.2 *Sheet Tests*

The sheet vinyls after thirty-two months soil burial were found to have undergone some superficial changes which included discoloration, shrinkage, warping, and insect attack. The discoloration, in general, (see Fig. 7) was similar to that previously mentioned for the wire coatings. One unusual color development was noted in the case of the compound prepared with chlorophenyl diphenyl phosphate (No. 120-67) which turned an overall pink.

Shrinkage and warpage was noted in samples where there had been an excessive loss in plasticizer as determined by analysis (see Table VI) or deduced from a large change in modulus. An example of shrinkage may be seen in the dioctyl adipate compound (No. 84-67) shown in Fig. 7; a noticeable difference in size between this and the other samples is readily apparent. Warping appears to be associated with samples which show a large increase in modulus or stiffness and suggests that the plasticizer loss may not be uniform over the surface of the samples. There was also an indication of nonuniformity of attack on vinyl wire coatings which was occasionally apparent as a variation in stiffness along a coating from which the conductor had been removed.

The insect attack on sheet vinyls was typical in that it was confined to the edges of the samples (see Fig. 8). Scalloped sections were removed from the edge of what were originally rectangular samples. This occurred on a relatively few samples and presented no problem in obtaining sound areas from which to punch tensile specimens. It is evident from these observations that prepunched specimens should be avoided as they are liable to edge damage, which would render them unsuitable for measurement.

Significant differences have been noted among the various vinyls with respect to their permanence, as reflected by tensile tests. Data

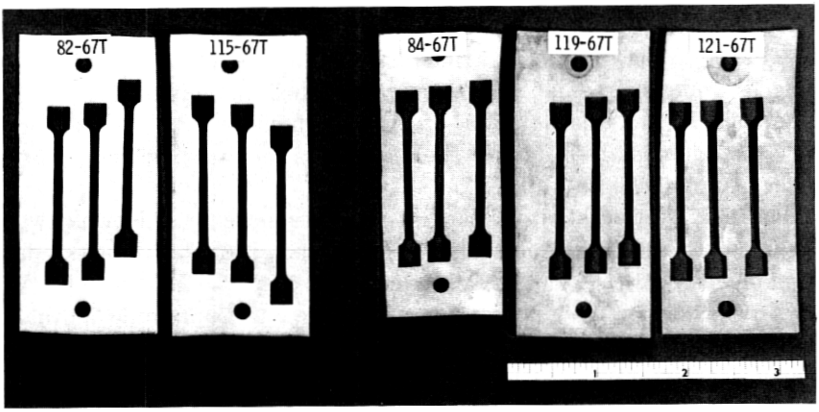

Fig. 7—Range in discoloration observed in vinyl sheet samples after 32 months soil burial in Georgia (cutouts are from micro specimens).

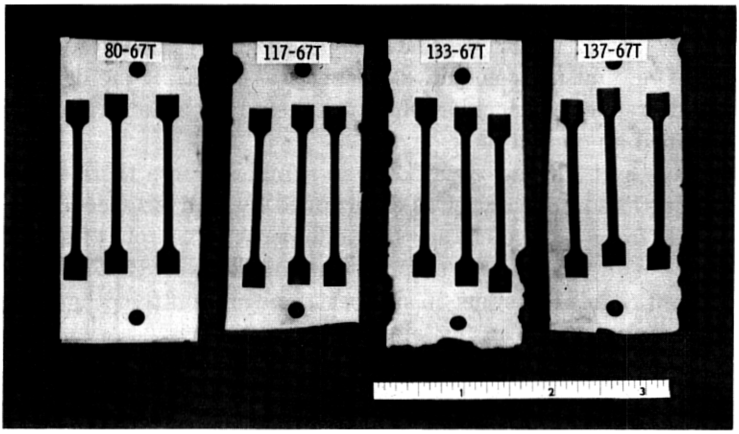

Fig. 8—Examples of edge damage by insects to vinyl sheet samples after 32 months soil burial in Georgia.

on the sheet samples are presented in Tables IV and V and Figs. 9, 10, and 11. The large increase in the moduli of those vinyls containing azelate and adipate esters (Nos. 83- and 84-67) was expected (see Fig. 9) since these plasticizers, which are known to be biodegradable, were included to provide assurance of the microbiological activity of the soil at the test sites. A large increase in modulus was also noted for the monomeric penta ester vinyl (No. 79-67) while compositions prepared with two dimer penta esters (Nos. 80- and 81-67) showed much smaller changes clearly confirming the superiority of the dimer as previously reported from data on wire coatings. Among the monomeric plasticizers, exceptional permanence was shown by both trioctyl and the mixed n-octyl n-decyl trimellitates (Nos. 115- and 116-67) as judged from their small changes in modulus. Although there is no difference in the tensile data of these trimellitates, plasticizer loss by extraction analysis favors the trioctyl trimellitate, which showed a very small loss (see Table VI).

The polyester plasticizers vary in their response to soil burial with the medium and high molecular weight types showing the best performance (Fig. 10). A notable difference was observed between the two low molecular weight polyesters with the one containing phthalic groups (No. 121-67) showing the best permanence. Since polyester plasticizers are proprietary materials of undisclosed composition, any generalizations with regard to performance are risky and only those with proven integrity may be depended upon.

TABLE IV—EFFECT OF SOIL BURIAL ON THE TENSILE PROPERTIES OF PVC PLASTICS

No.	PVC Plastic* Plasticizer, 65 phr	Tensile Strength				Elongation				S-100 Modulus			
		Orig psi	% Change After 32 Months			Orig %	% Change After 32 Months			Orig psi	% Change After 32 Months		
			Shelf	Topsoil	Subsoil		Shelf	Topsoil	Subsoil		Shelf	Topsoil	Subsoil
115-67	TOTM	2533	+5.5	+7.9	+8.3	353	−10.7	+4.2	−5.7	1480	+3.8	+8.3	+10.3
116-67	NODTM	2405	−8.3	+5.3	+2.8	300	0.0	+8.0	+4.3	1468	−9.2	+9.4	+3.2
80-67	DIPENTA Ester (A)	2533	+4.7	+8.3	+14.1	300	+13.3	+3.0	+2.3	1696	−0.1	+13.3	+18.8
81-67	DIPENTA Ester (B)	2507	+5.7	+13.6	+9.0	323	+5.3	+1.2	+0.3	1444	−0.2	+20.1	+20.2
82-67	DOP	2442	−0.8	+10.4	+10.8	350	+1.4	+5.4	+4.8	1140	−2.3	+11.7	+17.5
120-67	Chloro Aryl Phosphate†	3207	+5.3	+5.6	+5.9	307	+5.9	−5.5	−0.6	1760	+2.4	+20.7	+25.4
79-67	PENTA Ester	2492	+7.5	+26.6	+26.4	357	+0.8	−3.9	−7.5	1242	+2.6	+46.1	+55.3
83-67	DOZ	2119	+4.8	+26.0	+39.1	377	+2.1	+1.8	−6.4	968	−1.6	+38.1	+83.9
84-67	DOA	2109	+6.4	+38.5	+22.7	390	+2.6	−19.5	−12.7	876	+3.5	+110.7	+77.6
119-67	Polyester, high Mol. wt	2645	+1.9	+3.1	+5.1	320	+4.7	+0.6	+2.8	1749	−1.4	+12.6	+10.8
122-67	Polyester, high Mol wt	2489	+4.0	+6.7	+17.4	327	−8.3	−7.0	−6.1	1565	+7.1	+18.1	+8.5
118-67	Polyester, med mol wt	2815	−3.1	+3.7	+3.3	340	−4.4	−0.6	−8.0	1864	+1.9	+14.3	+14.6
121-67	Polyester, low mol Wt	3048	−1.6	+7.7	+9.5	350	0.0	−8.0	−9.4	1817	−1.2	+20.8	+21.2
117-67	Polyester, low mol Wt	2534	+2.4	+14.8	+21.5	333	+6.6	+2.1	+0.3	1396	+0.8	+36.3	+46.7

* Base formulation (pts by wt): PVC resin—100 pts; plasticizer (as indicated)—65 pts; dibasic lead phthalate—8.0 pts; low mol wt polyethylene—1.0 pt

† Chlorophenyl Diphenyl Phosphate

TABLE V—EFFECT OF SOIL BURIAL ON THE TENSILE PROPERTIES OF PVC PLASTICS

No.	PVC Plastic*		Tensile Strength				Elongation				S-100 Modulus			
	Plasticizer, 65 phr (Blends 45/20 phr)	Filler 50 phr	Orig psi	% Change After 32 Months			Orig %	% Change After 32 Months			Orig psi	% Change After 32 Months		
				Shelf	Topsoil	Subsoil		Shelf	Topsoil	Subsoil		Shelf	Topsoil	Subsoil
126-67	DOP/Nitrile Rubber	None	2195	−2.1	+1.0	+9.6	303	−4.3	+1.6	+11.5	1335	−2.2	−4.4	−0.1
128-67	DOP/Cl Hydrocarbon	None	3014	−6.5	+0.7	+0.6	383	−2.1	−7.3	−5.5	1504	−3.4	+6.0	+3.7
127-67	DOP/Cl Polyethylene	None	2580	+0.7	+9.3	+7.4	297	+4.4	+5.4	+6.4	1631	+1.8	+7.5	+7.0
124-67	DOP/Polyester M.M. Wt	None	2611	−5.4	+3.9	+9.6	367	−3.3	−7.6	+0.3	1215	−1.9	+16.5	+18.0
125-67	DOP/Polyester H.M. Wt	None	2422	+1.6	+13.7	+13.3	360	+9.7	−1.4	−3.6	1099	+1.0	+20.8	+23.7
130-67	TCP/Cl Hydrocarbon	None	3213	−5.7	−1.1	+0.4	347	−9.2	−13.5	−7.8	1836	−4.6	+7.8	+2.4
129-67	DIPENTA Ester/Cl Hydrocarbon	None	2751	+1.3	+5.7	+7.6	353	−2.3	−5.1	−3.1	1758	+2.2	+4.0	+11.3
131-67	DOP	$CaCO_3$, ppt	2120	−3.4	+9.4	+2.0	300	−8.3	−5.0	−1.7	1232	+5.7	+11.0	+5.0
132-67	DIPENTA Ester	$CaCO_3$, ppt	1994	−2.3	+4.0	+5.7	247	−10.9	+0.8	+4.0	1551	−0.8	+1.0	+1.4
133-67	DOP	$CaCO_3$, limestone	2270	−0.4	−0.4	−4.6	260	+26.9	+15.4	+17.3	1489	−15.3	−15.6	−17.1
134-67	DOP	$CaCO_3$, limestone†	2064	−2.5	−2.2	+4.3	277	+19.7	+18.1	+12.6	1194	−14.2	−16.1	−12.5
135-67	DOP	Clay, calcined	2000	−6.4	+0.6	+1.3	290	−1.7	−2.1	−4.5	1416	−5.6	−5.2	−1.6
136-67	DIPENTA Ester	Clay, calcined	1744	+6.7	+9.8	+11.3	170	+11.8	+19.4	+8.2	1628	+3.9	+4.7	+7.2
137-67	DOP	Hydrated Alumina‡	1710	+2.2	+9.5	+7.1	260	+11.5	+20.8	+12.7	1275	−1.7	−0.2	−2.9

* Base formulation (pts by wt)—PVC resin—100 pts; plasticizer (as indicated)—65 pts; dibasic lead phthalate—8 pts; filler (as indicated)—50.0 pts; low mol wt polyethylene—1.0 pt

† Treated with organic coating

‡ 65 phr

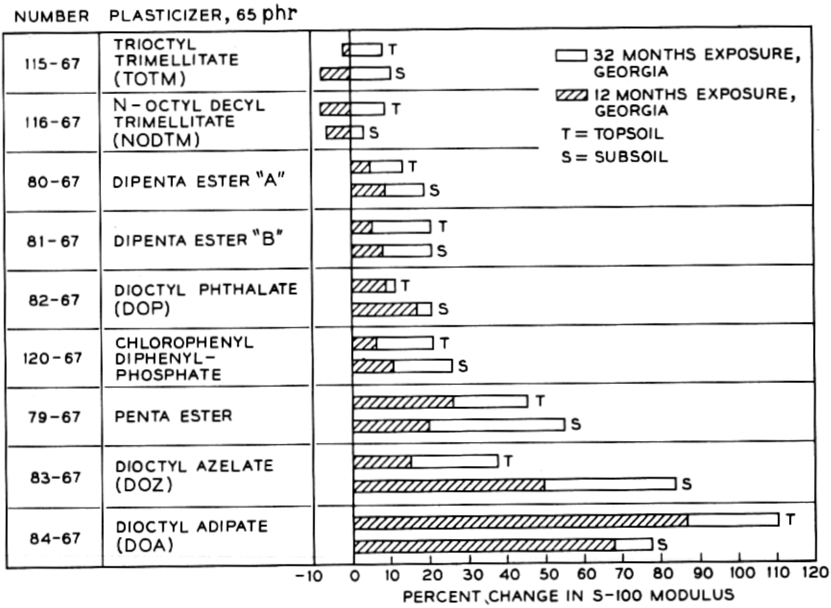

Fig. 9—Effect of soil burial on the modulus of sheet vinyls containing monomeric and dimeric plasticizers.

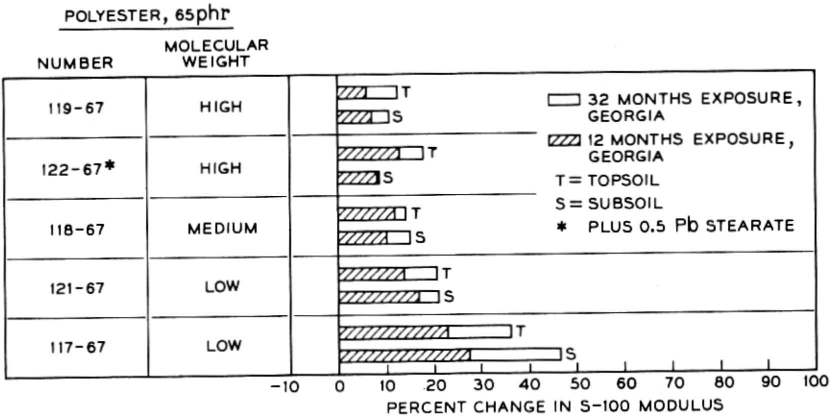

Fig. 10—Effect of soil burial on the modulus of sheet vinyls containing polyester plasticizers.

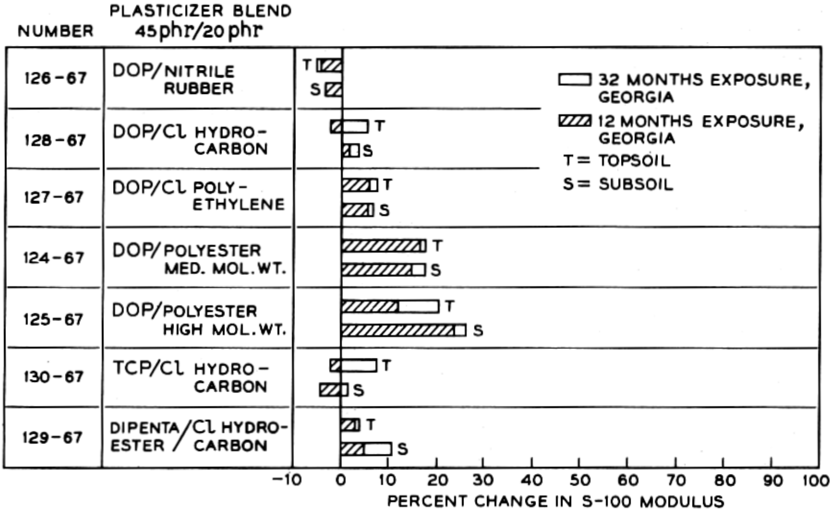

Fig. 11—Effect of soil burial on the modulus of sheet vinyls containing plasticizer blends.

Table VI—Plasticizer Analysis on Sheet Samples After Soil Burial

		Percent Plasticizer			
			32 Months Soil Burial, Ga.		Loss After Exposure (Avg)
No.	Plasticizer	Original	Topsoil	Subsoil	
115-67	TOTM	37.2	36.9	36.5	−0.48
116-67	NODTM	38.1	36.0	36.2	−2.07
80-67	DIPENTA ESTER "A"	37.2	36.7	36.2	−0.80
82-67	DOP	37.2	36.3	34.7	−1.69
83-67	DOZ	37.1	28.9	26.6	−9.35
84-67	DOA	37.0	27.0	26.3	−10.33
119-67	Polyester, high mol wt	38.9	34.6	34.0	−4.60
118-67	Polyester, med. mol wt	39.5	35.9	35.7	−3.75
121-67	Polyester, low mol wt	38.7	36.0	35.8	−2.82
117-67	Polyester, low mol wt	38.0	32.8	30.4	−6.44
128-67	DOP/Cl Hydrocarbon	37.3	36.2	35.8	−1.05
130-67	TCP/Cl Hyrdocarbon	37.4	37.1	37.3	−0.20
129-67	DIPENTA ESTER/ Cl Hydrocarbon	37.3	36.8	36.3	−0.78

A number of compositions exhibiting good permanence were prepared with plasticizer blends in which a strong primary was partially replaced with a secondary or less efficient plasticizer (Fig. 11). Where the replacements were nitrile rubber, chlorinated hydrocarbon, or chlorinated polyethylene, an improvement was observed over 100 percent of the primary (see Figs. 9 and 11). No advantage was observed in the use of polyesters in such blends.

The addition of high loadings of inorganic fillers does not seem to have had a critical effect on resistance to soil burial (see Table V). In general, the loaded compositions showed equal or superior permanence in tensile tests when compared with unfilled controls. The limited changes recorded correspond to those observed over the same period during shelf aging and are believed to reflect testing variables.

6.2 *Discussion*

The observed tendency of vinyl plastics to increase in stiffness or modulus with soil burial is in general agreement with the literature in which a loss in extensibility and an increase in tensile strength are reported. Results of this nature were obtained in studies made by the Bureau of Reclamation on 8–10-mil vinyl sheeting in seven-year accelerated laboratory soil burial tests and on samples taken from field service in Wyoming (seven years) and in New Mexico (four years).[6] A vinyl tape pipe coating plasticized with dioctyl phthalate was found by B. I. Borisov, et al., to have lower extensibility and higher tensile strength after five years burial on the Dashave-Minsk gas pipe line.[10] Infrared spectra of films pressed from the coating showed an intensification of hydroxyl and carbonyl bands. It was inferred by the authors that this resulted from oxidation of both the resin and the plasticizer induced by micro-organisms. This deduction is debatable since an attack on the resin would be expected to reduce strength rather than increase it, as observed, and, further, our experience has shown that dioctyl phthalate extracted from soil burial samples is unchanged. An alternate explanation for the intensification of these bands might be found in the possibility that fractions from a bitumen primer on the pipe line might have been absorbed by the vinyl tape to yield the observed spectra.

Where an increase in stiffness occurs in a vinyl it may be attributed to a loss in plasticizer and the magnitude of the increase is roughly proportional to the plasticizer loss (see Table VI). Plasticizer is believed to be lost through diffusion to the surface of the coating, followed by migration to the soil environment. Utilization of plasticizers by micro-organisms in their life cycle is recognized as a primary cause of plasticizer loss in vinyls.[11,12] It has been postulated that this utilization by both bacteria and fungi occurs as an interfacial absorption and that the micro-organisms do not, as a rule, penetrate the plastic mass.[1] This is believed to be the case since there is no evidence of the decomposition of the retained plasticizer or the presence of by-products that might result from such decomposition.

Other migration forces, such as those presented by soil minerals and water, should not be overlooked as causes of plasticizer loss. Powdered silicas and calcium carbonate in intimate contact with vinyl plastics have been shown to have the capability of removing plasticizer.[13,14] The extraction of plasticizer from vinyl plastics by water has been demonstrated to take place by E. F. Schultz, who investigated the variables involved.[15] In the case of both inorganic powders and water, when saturation conditions occur, the further removal of plasticizer is prevented. This might be a partial explanation for the leveling effects observed in Figs. 5 and 6.

VII. ENGINEERING IMPLICATIONS

From the results of these studies it is evident that both polyethylene and vinyl chloride plastics may be selected that resist soil degradation and maintain, to a high degree, their engineering properties after long-term soil burial. They cannot be expected, however, to provide, in all cases, completely continuous coatings over a conductor because of chance damage by macro-organisms. Thus, they represent a poor risk as a primary electrical insulation unless additional protection, for example, in the form of a metal foil, is forthcoming. As sheath or jacketing on buried wire and cable they may be expected to perform satisfactorily where an occasional discontinuity may be tolerated. In these applications they would offer mechanical protection and serve as a secondary insulation. Since the environmental resistance of properly selected polyethylene and vinyl chloride plastic are adequate, their selection for a given application will depend mainly on unrelated properties, such as toughness, low-temperature flexibility, or flammability.

VIII. CONCLUSIONS

8.1 *Polyethylene*

Polyethylenes show excellent resistance to decomposition after long-term soil burial. The principal changes observed in the tensile properties of the coatings are believed to result from alterations in their crystallinity with time and to be unrelated to the soil environment. Coatings prepared with low-density resins, in general, show only minor changes in tensile properties, whereas those prepared with high-density resins may suffer a severe loss in elongation.

The electrical insulation and capacitance of the coatings remained essentially constant, which is believed to reflect the absence of chemical change in these coatings. The decrease observed in the breakdown strength is attributed to chance mechanical damage which, in part, is the result of insect attack.

8.2 *Vinyl Chloride Plastics*

Vinyl chloride plastics vary with regard to their resistance to soil burial, depending primarily on their plasticizer content. The more permanent vinyls show a moderate initial increase in stiffness with time and then appear to level off while they still retain a high percentage of their original properties.

Among the recently examined plasticizers found to show promise in vinyls for soil burial are the trioctyl and n-octyl n-decyl trimellitate, and blends of nitrile rubber, a chlorinated hydrocarbon, and a chlorinated polyethylene with a primary plasticizer such as dioctyl phthalate. Confirmation was obtained for the superiority of the dimer esters of pentaerythritol over the monomeric esters and that vinyls prepared with polyesters may resist change on soil burial.

Loading vinyls with various types of inorganic fillers does not appear to have any significant effect on their resistance to soil burial.

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