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# Soil Burial Tests:

# Trends in Material Behavior After Eight Years of Soil Exposure

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*The preceding papers have presented detailed coverage of soil burial effects on specific classes of organic materials. This paper summarizes some of the trends which have emerged in the eight years of soil exposure in both acid and alkaline soil:*

(*i*) *High-density and black crosslinked polyethylenes, rigid PVCs, acrylics, polycarbonates, acetates, fluorocarbons, styrene polyesters, unfilled epoxy, neoprene without clay, and sulfur-cured nitrile rubber have been essentially unaffected.*

(*ii*) *Insect attack is confined to the soft forms of materials such as cellulosics, rubbers, and thermoplastics, specifically low-density polyethylene and certain plasticized poly(vinyl chloride) samples. All cast resins, structural laminates, and hard thermosetting plastics have been completely free of insect attack.*

(*iii*) *With both plastics and elastomers, significant losses in tensile strength are almost always accompanied by large decreases in insulation resistance.*

(*iv*) *Some plastic materials tend to increase in tensile strength due to the loss of constituents while some lose strength because of chemical breakdown. The reinforced thermosetting materials decrease in strength because of moisture penetration along the resin-fiber bond.*

(*v*) *Of the plasticized PVC wire insulations, the materials with trioctyl and octyl diphenyl phosphate, and dioctyl adipate blend, have shown significant increases in modulus indicative of plasticizer loss due to leaching and/or microbial consumption.*

(*vi*) *Unless there is chemical breakdown or biological damage, the strength losses of all molded plastics and many elastomers appear to level off, after four years of exposure, at about 25–45 percent.*

(*vii*) *Epoxy and phenolic adhesives for bonding reinforced polyester laminates were not severely attacked but rather laminate failure occurred in all cases. In contrast to this, bonds to stainless steel generally decreased in a straight-line relationship.*

(*viii*) *There has been no appreciable effect of 6-inch versus 18-inch depth on materials performance and no significant consistent difference between the two plots.*

## I. INTRODUCTION

It is difficult to pick out trends from the data discussed in the preceding papers but there are some trends that may aid design engineers in developing longer lasting structures for buried plant. The effects are categorized for discussion as follows:

(*i*) Moisture/property
(*ii*) Biological
(*iii*) Site and depth of burial

These effects also are shown in Table I.[1] The numbers in this table, however, are not exclusive (i.e., some materials may be affected in more than one way) and therefore are not additive.

## II. MOISTURE/PROPERTY CHANGE

A minimum of one-third of the materials in any one class in Table I (except the adhesives and thermoplastics) has shown a significant property change (arbitrarily chosen as $\geqq$ 25 percent) due to chemical or moisture influences. For instance, the effects of soil burial on the insulation resistance of certain elastomers and thermoplastics and thermosetting plastics is shown in Table II. The plastic materials that have markedly changed are the cellulosics, polyamide type 6, melamine glass, styrene polyester glass, alkyd glass, the silica-filled styrene-butadiene copolymer, and all the elastomers except the natural rubber jacket. With the exception of the cellulosic esters, the polyamides which can undergo hydrolysis, and possibly the styrene materials, the dc resistance of thermoplastic compounds has not been affected by soil burial. In contrast to this, it is very apparent that all the thermosetting materials, phenolics, diallyl phthalates, melamine, styrene polyester glass, alkyd and styrene-butadiene glass, which can absorb considerable

TABLE I—FACTORS FOUND TO CAUSE DEGRADATION OF PLASTIC AND ELASTOMERIC MATERIALS

| Class of Materials | Number of Materials | Affected by | | | Materials in Categories | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Depth | Site | | Moisture/Property* | | Microorganisms† | | Rodents | | Insects | |
| | | | Ga | NM | No. Affected | % Affected | No. Affected | % Affected | No. Affected | % Affected | No. Affected | % Affected |
| *Tensile Bar or Sheet* | | | | | | | | | | | | |
| Thermoplastic | 28 | No | No | No | 7 | 25 | 3 | 13 | 1 | 4 | 13(0) | 46 |
| Thermosets | 10 | No | No | No | 3 | 33 | 0 | 0 | 0 | 0 | 0 | 0 |
| Casting Resins | 3 | No | No | No | 1 | 33 | 0 | 0 | 0 | 0 | 0 | 0 |
| Rubber | 17 | No | No | No | 8 | 47 | 9 | 53 | 0 | 0 | 10(2) | 59 |
| Pressure Sensitive Tapes | 4 | No | Yes | No | 3 | 75 | 1 | 25 | 0 | 0 | 1(0) | 25 |
| *Plastic Insulation* | | | | | | | | | | | | |
| Polyethylene | 18 | No | No | No | 7 | 39 | 0 | 0 | 0 | 0 | 17(6) | 94 |
| Poly (Vinyl Chloride) | 15 | No | No | No | 5 | 33 | 8 | 53 | 0 | 0 | 12(2) | 87 |
| Rubber | 18 | — | — | — | 11 | 61 | 15 | 83 | 0 | 0 | 15(11) | 83 |
| *Reinforced Plastic Laminates* | | | | | | | | | | | | |
| Structural Grade | 20 | No | No | No | 12 | 60 | 0 | 0 | 0 | 0 | 0 | 0 |
| Electrical Grade | 23 | No | No | Yes | 23 | 100 | 2 | 8 | 0 | 0 | 2(1) | 8 |
| *Adhesives* | 15 | No | No | No | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

* Based on mechanical or electrical changes $\geq 25\%$.
† Based on known susceptibility.
( ) Destroyed.

TABLE II—DC INSULATION RESISTANCE OF PLASTICS AND ELASTOMERS

| Materials | Orders of Magnitude of Change — Years of Exposure 1 | 2 | 4 | 8 |
|---|---|---|---|---|
| *Thermoplastics* | | | | |
| Cellulosics (4)* | 0 | 0 | 2 | ½ |
| Styrenes (2) | ½ | 1½ | ½ | ½ |
| Acrylics (3) | 0 | 0 | 1 | 0 |
| Polyolefins (2) | 0 | 0 | 0 | 0 |
| Poly (Vinyl Chloride) (2) | 0 | 0 | 0 | 0 |
| Polycarbonate (1) | 0 | 0 | 0 | 0 |
| Acetals (2) | 0 | 0 | 0 | 0 |
| Fluorocarbon Polymers (2) | 0 | 0 | 0 | 0 |
| Polyamides (2) | 2 | 2 | 2 | 2 |
| *Thermosets* | | | | |
| Phenolics (4) | 1½ | 1 | ½ | 1 |
| Diallyl Phthalates (2) | 1 | 2 | ½ | 1 |
| Melamine, Glass (1) | 3 | 3 | 2 | 3 |
| Styrene Polyester, Glass (1) | 3 | 3 | 3 | |
| Alkyd, Glass (1) | 2 | 2 | 3 | |
| Styrene-Butadiene Copolymer (1) | 3 | 4 | 4 | |
| *Elastomers* | | | | |
| Natural Rubber Insulation | −5 | | | |
| Natural Rubber Jacket | −0 | | | |
| SBR Insulation (3) | −½ | | | |
| SBR Jacket | −2½ | | | |
| Neoprene Jacket, Type W, MgO | −2½ | | | |
| Neoprene Jacket, Type W, red lead cure | −2½ | | | |
| Neoprene Jacket, Type W, with red lead cure and zinc salt of dimethyl dithiocarbamic and zinc salt of 2 mercaptohenzo thiozole | −3 | | | |
| Butyl Rubber Insulation | −3½ | | | |
| Chloro-Sulfonated Polyethylene | +½ | | | |
| Silicone Rubber | −6 | | | |

* Number of different formulations in the group.

amounts of water by wicking, for example, have lost significant dc insulation resistance. In line with these trends, Fig. 1 shows the tensile strength changes of some of the poorer materials. In a soil environment, the thermoplastic materials that do show significant changes tend to increase in strength due to loss of plasticizers, lubricants, etc. The cellulosics may contain dibutyl sebacate which has shown a tendency to leach from the material. The thermosetting materials which have reinforcing material in the form of particulate or fibrous fillers, etc., lose tensile strength due to water absorption along the interface of the matrix and reinforcing material. It appears that most of the materials that have shown large losses in dc resistance have also shown large losses in tensile strength. No material lost significant tensile strength that did not also show a large insulation resistance loss.

Another rather pronounced trend shown in Fig. 1 is that the tensile strength losses appear to have leveled off between the fourth and eighth years. Of course, the long-term trend will be better defined after the 16-year inspections in 1974 and 1976.

The insulation resistance of the elastomer insulated or jacketed wires exposed for only one year at Bainbridge was generally poor. As shown in Table II, natural rubber insulation, SBR jacket, all the neoprenes (with and without fungicides), butyl rubber, and silicone rubber failed badly after only one year. Table III lists the range of tensile strength losses for 17 elastomers and, as with the plastic materials, no significantly large change in tensile strength occurred without an accompanying large drop in insulation resistance. A plot of the tensile data is shown in Fig. 2 and, as with the plastic tensile data, appears to be leveling off in some materials. The exceptions, of course, are the ester-based polyurethanes which failed completely between the second and

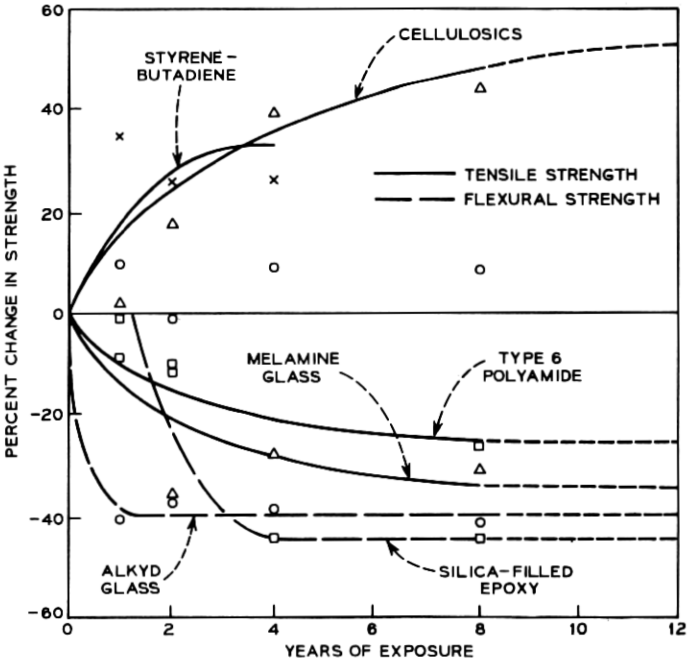


Fig. 1—Strength changes of plastic materials versus soil exposure time.

TABLE III—TENSILE STRENGTH REDUCTIONS IN ELASTOMERIC COMPOUNDS AFTER UP TO EIGHT YEARS OF SOIL BURIAL EXPOSURE

| Material | Tensile Strength Loss – % | | | | |
|---|---|---|---|---|---|
| | +15–0 | 1–15 | 16–25 | 26–50 | >51 |
| Natural Rubber, black | | | | | √ |
| Styrene-Butadiene Copolymer | | | √ | | |
| Polychloroprene, with clay | | | | | √ |
| Polychloroprene, no clay, black | | √ | | | |
| Nitrile Rubber, sulfur cure | √ | | | | |
| Nitrile Rubber, heat resistant | | | √ | | |
| Butyl Rubber, sulfur cure | | | | √ | |
| Butyl Rubber, quinoid cure | | | | √ | |
| Polyethylene, low density, crosslinked, black | √ | | | | |
| Polyethylene, crosslinked, black | | √ | | | |
| Polyethylene SBR, crosslinked, black | √ | | | | |
| Polyurethane, ester based, black | | | | | √ |
| Polyurethane, ether based, black, sulfur cure | | √ | | | |
| Ethylene Propylene Copolymer, peroxide cure, black | | | √ | | |
| Chloro-Sulfonated Polyethylene | | | √ | | |
| Ethylene Propylene Terpolymer, sulfur cure | | | | √ | |
| Ethylene Propylene Terpolymer, sulfur cure, clay loaded, black | | | | √ | |

fourth years and natural rubber which appears to be steadily decreasing.

Unfortunately, not all of the elastomeric materials tested for tensile strength retention were evaluated for insulation resistance. However, the tensile data for natural rubber, neoprene loaded with clay, ester-based polyurethane, and butyl rubber are in complete agreement with the insulation resistance data.

Of the 23 types of electrical-grade laminates based on phenolic, melamine, silicone, epoxy, and polyester resins each suffers a large decrease in insulation resistance, which may be as high as 90 percent, while showing only moderate decrease in flexural strength. Since these materials are thin and contain some form of reinforcing, the effects of water have been magnified. These materials are clearly not suitable for direct soil burial.

Structural-grade epoxy and polyester type laminates exhibit the same degree of mechanical degradation and after eight years maintained 65 to 70 percent of their initial flexural strength. The laminates with fiber glass cloth reinforcement retained 80 to 85 percent of their strength and have superior resistance to soil burial than all the other methods of reinforcement (such as chopped strand mat which lost 40 to 45 percent of its strength).

The epoxy and phenolic type adhesives for bonding polyester-based laminates performed well since laminate failure occurred in all cases between the first and second layers of glass mat. This, of course, meant that what was being measured was the interlaminar shear strength plus the tensile strength of a single ply of the substrate. The results indicate that these adhesives were not severely attacked by these environments. Even with good surface treatments, epoxy-bonded stainless steel shear lap specimens continue to lose their ultimate load bearing capacity with time. However, since the initial strength levels are well above typical requirements, they would be expected to perform satisfactorily with proper joint design.

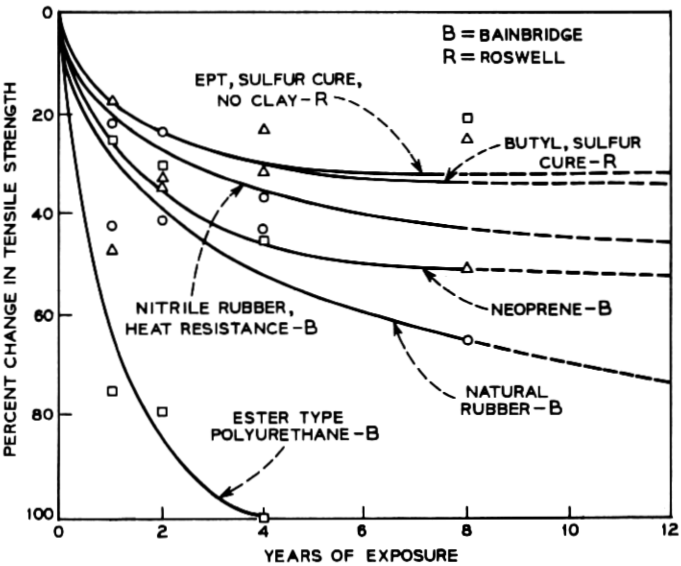


Fig. 2—Tensile strength changes of elastomeric materials versus soil exposure time.

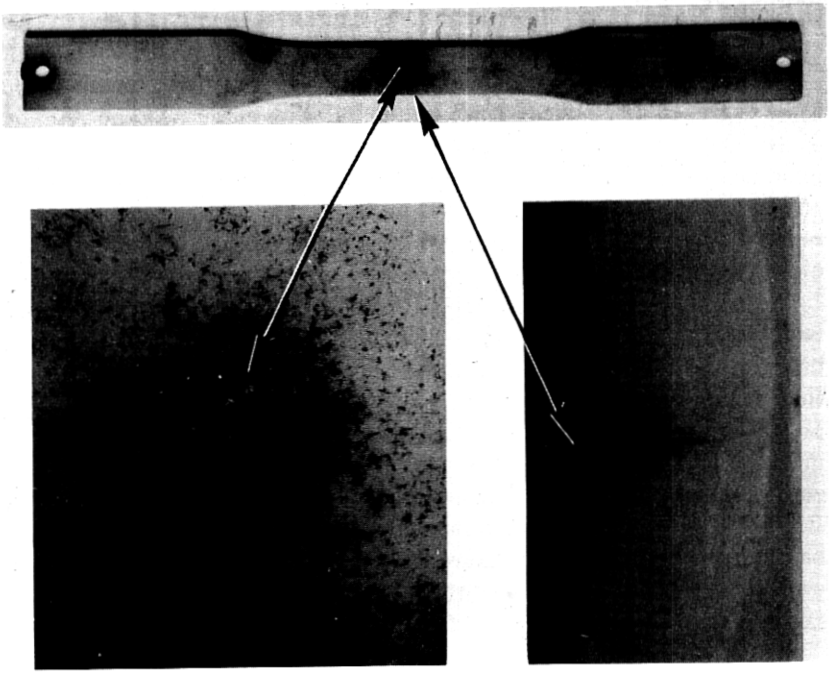

Fig. 3—Ester-based polyurethane with pronounced fungal attack.

Of the four adhesively backed tapes evaluated in this program, both the vinyl and rubber types have maintained sufficient strength after up to eight years and should continue to do so while the glass type has shown large losses in tensile strength and erratic adhesion and the aluminum tape has been damaged by corrosion. These last two are therefore not recommended for direct soil burial, except for short-duration applications.

## III. BIOLOGICAL PROPERTY CHANGE

The results of this program to date generally support the work in the literature relating to biological damage.

Table I also shows the materials affected by fungi. The best example of this is the molded ester-based polyurethane which, after two years in Roswell, showed considerable surface fungal growth. This growth can be seen on Fig. 3 in the form of black discoloration. A closer examination shows penetration over half-way through the sample. Interestingly, the tensile strength of this material had not been significantly reduced after two years, but after four years there was a loss of 26 percent. In the future, if the fungal attack continues as expected, the strength and other properties will continue to be degraded significantly.[2] Another good example is the wood flour filled phenolplastic tensile sample which, after eight years of exposure, showed a dimpled surface (Fig. 4). Initially, these samples had a resin-rich surface with essentially no wood flour exposed. With the absorption of water, the thin surface layer of resin fractured due to expansion and the wood flour was exposed to the environment. Subsequently, decay started and resulted in the white mycellia shown in Fig. 4.

With respect to insect damage, the results in this study are in agreement with those of Flateau,[3] and Gay and Wetherly.[4] The former has found over a 1- to 20-year period in Australia that rigid PVC, high-density polyethylene, and polyesters are highly resistant while natural rubbers, polyurethane, and plasticized PVC, cellulose acetate, and the

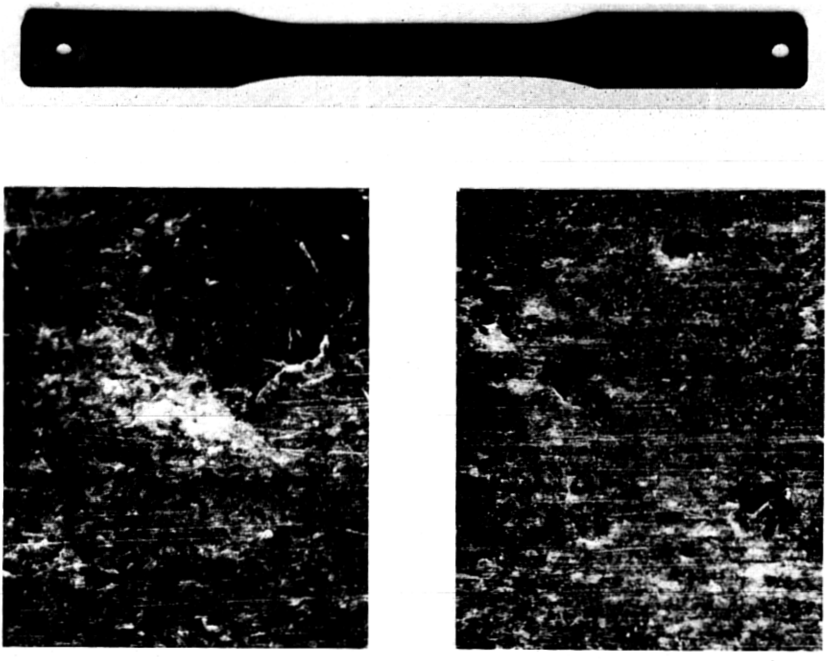

Fig. 4—Phenolplastic (one-step, wood flour) after eight years of exposure showing dimpling of the surface. Enlargement on the right shows several dimples and the one on the left shows the cracked resin and white fungal growth.

synthetic rubbers are moderately resistant to nonresistant materials, Gay and Wetherly report that few plastic materials in common use are immune to attack while materials such as plasticized PVC, polyethylene, and cellulose are liable to severe damage. Figure 5 shows the edge type

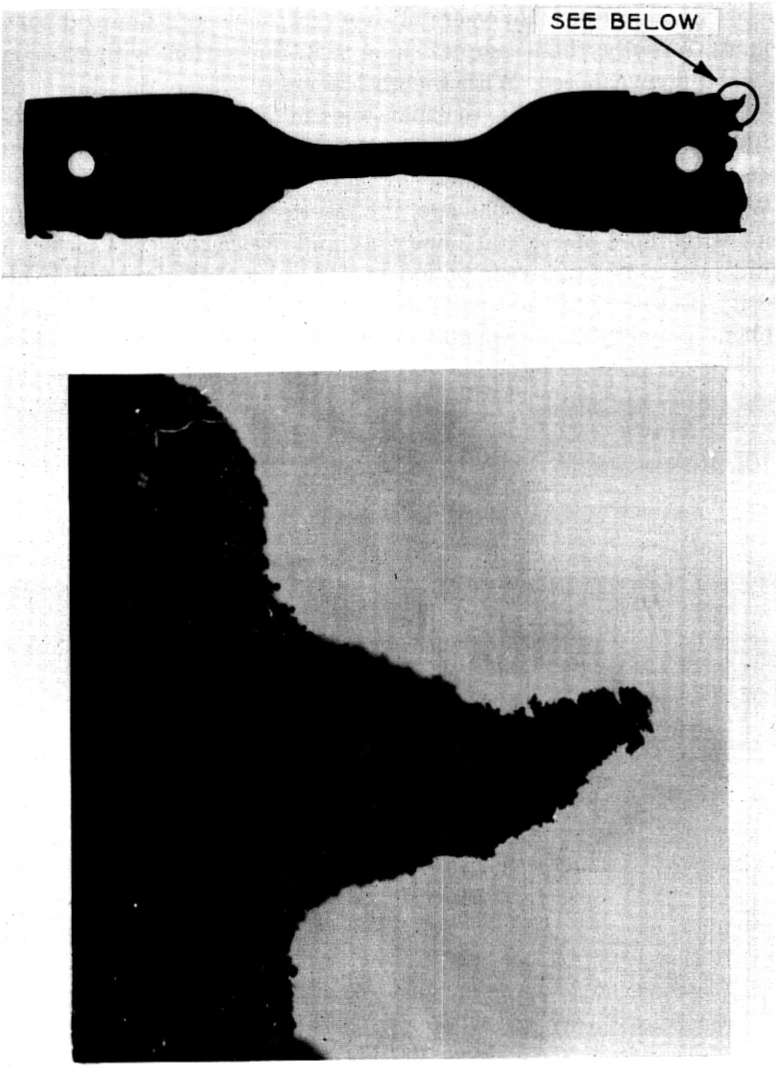


Fig. 5—Clay-loaded neoprene illustrating insect attack at edges (3/4X) and typical tufted appearance (25X).

of insect damage observed on many samples. The tufted pattern is typical.

Table I shows that about 32 percent of those samples with insect attack (does not include any casting resins or plastic reinforced laminates) failed. If the total number of materials is considered, 20 percent failed because of insects. Failure in the case of the insulated conductors means exposing bare metal while in the case of the tensile samples it means chewing completely through the sample.

Although other studies[5–8] have demonstrated that thermoplastic and elastomeric materials are susceptible to rodent damage, essentially none occurred in this program. This is due to the low population density of the animals at the test sites and the lack of the long horizontal trenches made in cable laying that tend to attract rodents. Consequently, from the design standpoint, the data in Refs. 5–8 probably provide the more reliable information with regard to animal damage.

The observations of Berk, et al.,[9] show that certain plasticizers are susceptible to fungal attack. Their findings are supported by those of the U. S. Office of Scientific Research and Development[10] which has also reported heavy fungal growth in some materials. Selected phthalates trimellitates as well as blends of nitrile rubber may be expected to give adequate service in the soil. It appears that the plasticizer loss rate in these materials has leveled off or even slightly decreased. This suggests, with these particular plasticizers, either that microbial attack is not a major contributor to degradation or that they must migrate to the surface before microbial degradation can begin.

## IV. EFFECT OF SITE AND DEPTH OF BURIAL

Although the chemistry of the two plots is markedly different, with very few exceptions no significant difference in materials behavior occurred during the eight years of exposure. However, it should be recognized that the averaging and grouping of materials tends somewhat to obscure the effects of soil burial on individual materials. Even so, some clear-cut changes did occur. For instance, the phenolic, melamine, silicone, epoxy, and polyester electrical-grade reinforced plastic laminates suffered more in the alkaline environment of Roswell than in the Georgia exposure. Direct soil burial of these laminates is not expected nor were they specifically designed for this environment. The aluminum pressure-sensitive tape corroded in the acid environment but was essentially unaffected in the mildly alkaline New Mexico soil. This is typical behavior for aluminum.

The effect of depth of burial, 6 inches and 18 inches, was virtually undetectable. In view of the rather small depth difference of 12 inches, this is not difficult to accept, especially since the site difference, which is much greater, also had little effect. This, however, does not mean that with some soils there may not be a difference; for example, soils with a high water table, etc., or different soil profiles.

## V. CONCLUSIONS

Based on up to eight years of soil exposure, the following trends can be identified with respect to the performance of plastic and elastomeric materials:

(*i*) The materials that have been essentially unaffected by soil burial to date include high-density and crosslinked polyethylenes, rigid PVCs, acrylics, polycarbonates, acetals, fluorocarbon polymers, neoprene without clay, styrene-polyester and unfilled epoxy, and sulfur-cured nitrile rubber.

(*ii*) Insect attack is confined to the softer materials such as cellulosics, rubbers, and thermoplastics, specifically low-density polyethylene and certain plasticized poly(vinyl chloride) samples. All cast resins, structural laminates, and thermosetting plastics have been completely free of insect attack.

(*iii*) There has been no significant rodent attack on these materials or their supporting polyethylene tubes. This is mainly attributable to the low population density of these animals in the test areas.

(*iv*) With both plastics and elastomers significant losses in tensile strength are almost always accompanied by large decreases in insulation resistance.

(*v*) Some thermoplastic materials tend to increase in tensile strength due to the loss of constituents such as plasticizers, which results in embrittlement, while the reinforced materials decrease because of the moisture migration along the resin-fiber bond.

(*vi*) Of the plasticized PVC wire insulations, the compounds containing trioctyl and octyl diphenyl phosphate, dioctyl adipate blend, tricresyl phosphate, or dioctyl phosphate have shown significant increases in modulus, indicative of plasticizer loss due to leaching and or fungal consumption.

(*vii*) Nearly all elastomers exhibited large losses in insulation resistance while natural rubber, butyl rubber, clay-loaded neoprene, ester-based polyurethane, and the sulfur-cured ethylene propylene terpolymers with and without clay exhibited tensile losses of greater than 25 percent.

(*viii*) The strength losses of all plastics appear to level off after four years of exposure at about 25 to 45 percent. This also seems to be true of the elastomers except for those materials shown to fail in soil environment.

(*ix*) There has been no appreciable effect of the 6-inch versus 18-inch depth on materials performance nor a significant consistent difference between the two test plots.

## VI. ACKNOWLEDGMENTS

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