FIELD AND LABORATORY AGING OF POLYMERIC DISTRIBUTION CABLE TERMINATIONS: PART 1-FIELD AGING

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ABSTRACT

This, two-part paper, describes the results of a research project aimed at understanding the magnitude of aging of polymeric cable terminations used in distribution. The termination types evaluated are currently used; hence, they have satisfied IEEE Standard 48. This standard does not address the issue of aging. Terminations made from 3 different polymer families and porcelain were evaluated. Presented in Part 1, are the results of field aging from 5 outdoor sites in the USA over a 3 year period; and in Part 2, results from accelerated aging fog chamber laboratory tests.

The results from field aging show that only minor changes were produced. Some differences were observed in the electrical performance of formulations within the same polymer family, and among different polymer families. However, it was concluded that the performance of the terminations evaluated would not be compromised by aging produced changes in the weathershed housing.

Key Words: Aging, weathering, leakage current, hydrophobicity.

1. INTRODUCTION

Cables used for underground power delivery can be connected to overhead lines at the riser poles via devices called Terminations. The terminations should satisfy the important requirements of (1) mechanical integrity - provide complete protection of the cable insulation from direct exposure to weathering agents; and (2) electrical integrity - withstand the operating voltage and other transient over voltages during service.

Polymers are the materials of choice for outdoor terminations for underground and other high voltage distribution cables. This is due to several significant advantages they offer over porcelain, such as, light weight, good vandal damage resistance and ready availability. In addition, polymeric cable terminations have provided users with highly simplified application techniques that have made them reliable and less expensive than porcelain. Polymeric material families widely used for cable termination housing are silicone rubber, ethylene propylene rubber (EPR) and ethylene-vinyl acetate (EVA). Due to the initially low surface energy which discourages water filming, commonly referred to as "hydrophobicity", polymers also offer higher resistance to leakage current and hence a superior contamination performance compared to porcelain.

PE-745-PWRD-0-06-1997 A paper recommended and approved by the IEEE Insulated Conductors Committee of the IEEE Power Engineering Society for publication in the IEEE Transactions on Power Delivery. Manuscript submitted December 2, 1996; made available for printing June 9, 1997.

On the negative side, owing to their organic nature, polymers can be more susceptible to changes from weathering agents and electrical discharges than porcelain. The presence of contamination and moisture on the surface promotes leakage current, which can lead to discharges. Persistent discharge activity can degrade the polymer housing. Weathering agents, such as, UV in sunlight, heat, chemicals, etc., act synergistically to accelerate the degradation. The reduction in the integrity of the device, referred to as aging, can shorten the expected life. Aging induced failures can occur via two different mechanisms - housing material degradation by tracking or erosion, and flashover at the service voltage.

Polymeric cable terminations were first introduced about 30 years back. New materials/formulations, designs and application techniques have been steadily introduced during this period. Like most electrical apparatus, the desired life expectancy of terminations is greater than 30 years. This level of experience does not exist currently. Service experience has been largely successful with only few failures experienced in extremely harsh locations [1].

Of vital importance, but is missing in the literature, is the knowledge of aging produced changes on the performance of terminations. Information like how much degradation is permissible before the performance of the termination is compromised, is unknown. Part of the reason is the lack of a systematic study aimed at answering this question.

The present project was initiated with the following goals:

1. For the widely used polymeric cable terminations, to determine the magnitude of the aging problem, and whether it is truly a serious concern.
2. To develop a meaningful accelerated aging laboratory test based on field experience data, and that could be performed with reasonable resources.

Location	Contamination Type	Perceived Contamination Severity	Additional Site Features
1. Whidbey Island, Washington (WA)	Sea salt, fertilizers	High	Test pole 10 m from Puget Sound, large temperature and humidity variations
2. Phoenix, Arizona (AZ)	Industrial, desert sand, vehicular deposits	Moderate	High UV and average temperature, avg. UV radiation 334 MJ/m^2
3. Austin, Texas (TX)	Nothing particular	Light	Typical of outdoor locations
4. Sea Island, Georgia (GA)	Coastal	High	Extensive corrosion of metal hardware in test site, about 150 m from Atlantic ocean
5. Augusta, Maine (ME)	Road salt, frequent fog	High	Periodic greasing of porcelain to prevent frequent flashover

Table 1: Some Information on Outdoor Test Sites

2. DETAILS OF OUTDOOR TEST SITES

To understand the aging problem experienced in service, it was decided to install terminations at test sites in various locations in the continental USA. Five locations were selected for this project, and are shown on the map in Fig. 1. The test sites were selected to cover a range in the type and severity of contamination. Four of the five sites were chosen for a particular service condition that was relatively more severe than normally encountered. It was felt that if satisfactory performance was obtained in a location with higher contamination severity of certain kind, then this termination type could be expected to perform better in other areas with similar contamination but of lower severity.

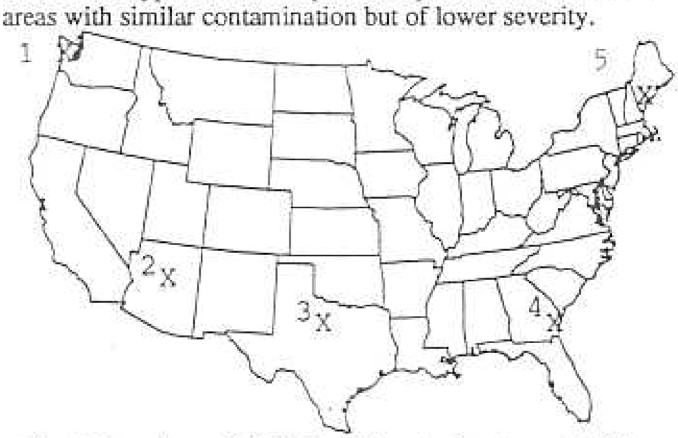

Fig. 1: Location of Field Test Sites in Continental USA.

Contaminated locations generally constitute a small percentage of a utility's service area; the majority can be characterized by mild to light contamination. This is true for many utilities worldwide. Therefore, it was felt necessary to have a test site representative of the majority of outdoor locations. The site is Austin, Texas was believed to be in this category. A brief description of each test site is included in Table 1. The perceived contamination severity shown in the Table is based on operating experience of the local utility serving the area.

3. TERMINATIONS EVALUATED

The terminations evaluated are commercially available; hence, they have satisfied IEEE Standard 48 [2]. The housing material families employed were silicone rubber, EPR and EVA. Porcelain terminations were used as a reference. Some details of the terminations are shown in Table 2. It can be seen that there is a significant variation in the leakage distance used for the same voltage rating. Some Type B terminations, exposed for 10 years in an industrial site in a cold climate, were made available and evaluated to obtain more information on field aging. All terminations had built-in electric stress grading cone or tube.

Table 2: Some Details of Terminations Evaluated

Identification	Housing Material	Leakage Distance (mm)		
		15 kV	25 kV	34 kV
A	EVA	305	591	1066
B	Silicone Rubber	349	501	679
C	EPR 1	330	NT	NT
D	EPR 2	508	508	914
E	Porcelain	355	470	698

Note: NT: Not included in the test.

The voltage (line to line) rating of the terminations evaluated was dependent on the local utility practice. The voltage rating was 15 kV in Arizona and Washington sites ; 15 kV and 25 kV in Georgia (two separate sets of terminations were evaluated); and 35 kV in Maine. The terminations were energized at their rated line to ground voltage. The site in Texas had 15 kV rated terminations energized at a value corresponding to 25 kV L-L voltage, in order to see if the higher electric stress accelerates the aging. The results indicated that there was no acceleration during the test period.

The terminations were installed (by experienced utility personnel) on the ends of a 5m long conventional concentric

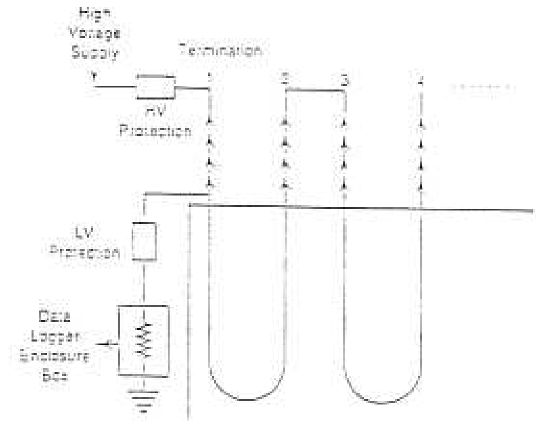

Fig. 2: Schematic of Test Set-Up in Field Sites.

neutral distribution cable bent to a U shape. Both ends of each cable section had the same termination type. A schematic of the test arrangement is shown in Fig. 2. In order to facilitate leakage current monitoring of individual terminations, the ground strap was separated from the concentric neutral and grounded via a precision resistor. A photograph of one test site is shown in Fig. 3.

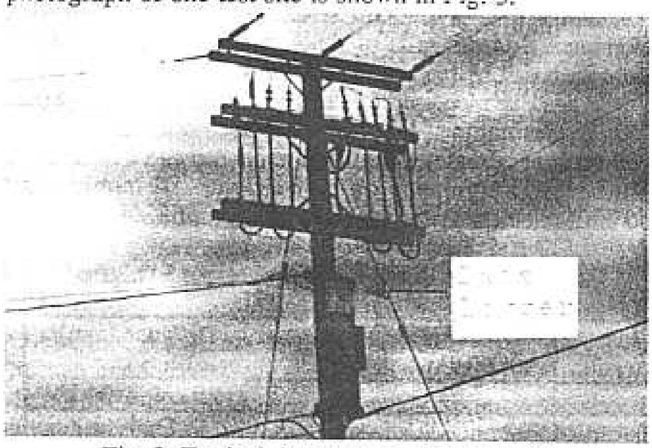

Fig. 3: Typical Arrangement in a Test Site

4. FIELD DATA MONITORED

Surface discharges resulting from leakage current can cause most harm to polymers. Therefore it was deemed important to monitor leakage current. However, leakage current changes alone may not fully explain the aging of polymeric devices [3]. Therefore it was decided to monitor certain aspects of material properties as well, by periodically cutting small sections from the housing and analyzing them in the laboratory. If a strong correlation of the material changes with electrical performance could be established, it might provide a means to assess the condition and predict end of life of polymeric insulating devices.

4a. Leakage Current

The leakage current was obtained by an on-line data acquisition system, shown schematically in Fig. 4. The voltage drop across the precision resistor which is proportional to the leakage current in the termination is input to a data logger, via appropriate surge suppressing devices to protect the instrumentation during accidental flashover. Coaxial shielded cables were used for connections to the data logger.

Four of the five sites were equipped with a data logger (Campbell Model 21 X) for leakage current monitoring. The data logger has the capacity to handle 16 channels with a maximum sampling frequency of 5 kHz, a 64 K memory card, and is enclosed suitably for outdoor use. The leakage current was sorted into different bins. In addition the highest peak and the time of occurrence was also obtained on a daily basis. The data was transmitted via a telephone line to a computer located at Arizona State University, where the data was also stored. The computer was programmed such that it was capable of remotely changing the threshold magnitude of bins, sampling frequency, the interval between data dumps, and the time of data transfer. To eliminate capacitive current and noise, a threshold of 1 mA was set as the minimum value for data processing.

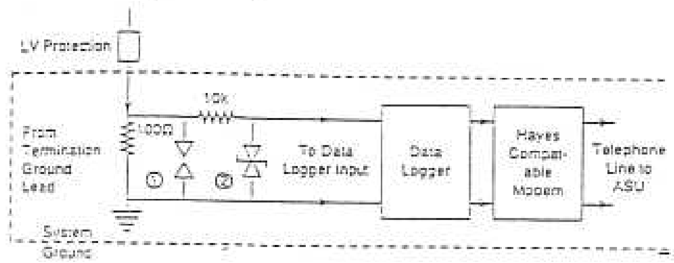

Fig. 4: Schematic of Data Acquisition System.

The field station in Georgia was an existing test site in a substation that did not lend itself for continuous leakage current measurement. Instead, periodic measurement of the watt-loss was performed by a technique described earlier [4], from which the leakage current can be determined. This measurement was performed manually and only under favorable weather. It was expected that if there were gross changes in the material, the increased polarity of the material would lead to additional moisture pickup and hence a higher watt loss.

4b. Material Analyses

To determine the aging produced changes, small pieces (1 cm^2) were cut from the skirts of the housing for material evaluation. The size of the samples required was small, so the terminations could be subjected to further field exposure without any problem. The techniques used were Infra-Red (IR) Spectroscopy and Cross Over Voltage (COV) measurement in a Scanning Electron Microscope. More details of these techniques and the equipment used have been described in recent papers [5, 6].

Table 3: Salient observations after 3 years of field exposure.

Termination	Arizona	Washington	Texas	Georgia	Maine
A	medium-good hydrophobicity	medium-good hydrophobicity	medium-good hydrophobicity	medium-good hydrophobicity	medium-good hydrophobicity
B	good hydrophobicity	good hydrophobicity	good hydrophobicity, spotty mold growth	good hydrophobicity, spotty mold growth	good hydrophobicity
C	hydrophilic	hydrophilic	hydrophilic	hydrophilic, hardware weathering stain near HV electrode	Not tested
D	Chalking, cracking due to UV, minor erosion on shank, hydrophilic	hydrophilic	Chalking, crazing, hydrophilic	Chalking, crazing, hydrophilic, hardware weathering stain on several sheds	Chalking, crazing, underside of sheds almost black, hydrophilic
E (Porcelain)	Cleaner than the rest	Cleaner than the rest	Cleaner than the rest	Cleaner than the rest	Cleaner than the rest

The COV value with reference to the data on the virgin sample provides an indication of the change in surface wettability. COV >900 eV is indicative of a hydrophobic surface, COV <300 eV is indicative of a completely wettable surface, and intermediate values can be used to estimate the reduction in surface hydrophobicity. IR spectroscopy was used detect both surface, as well as, sub-surface changes produced by aging. The changes are indicated by difference in height of the transmittance peaks at wavelengths characteristic of the polymer, with virgin sample data as reference.

5. RESULTS AND DISCUSSIONS

5a. Visual Observations.

Salient visual observations made after 3 years of field aging are listed in Table 3. More details are provided below:

1. There were no failures, or any apparent degradation serious enough to suggest failure.
2. The surface of all the new polymer terminations was hydrophobic. Field exposure caused changes in the wetting pattern. For EPR termination C and D, the surface was completely wettable in periods ranging from 9-12 months and 1-3 months of field exposure, respectively. The hydrophobicity of Terminations B (including the previously field exposed samples) was virtually unchanged from the new condition. The hydrophobicity of Termination A was better than Termination C but not as good as B.
3. Chalking and crazing from UV exposure was apparent only on EPR termination D and was noticeable within 6 months of exposure in all sites. In addition, Termination D in the Arizona site had minor erosion (not serious enough to cause alarm) on the shank.
4. The field response of the two EPR terminations was significantly different. This should serve as a caution against characterizing electrical performance by simple generic terms, like polymer family.
5. Mold growth in the form of black spots were observed on the silicone rubber termination B in Georgia and Texas, both regions being characterized by high relative humidity (RH) and average daily temperatures (subtropical environment). It is interesting to note that in the Arizona site with high temperature but low RH, and in the Maine Site with high RH, but low temperature, there were no mold growth. The mold growth was sporadic and did not affect either the leakage current or the integrity of the terminations.

Fig. 5 shows terminations after the 3 field exposure.

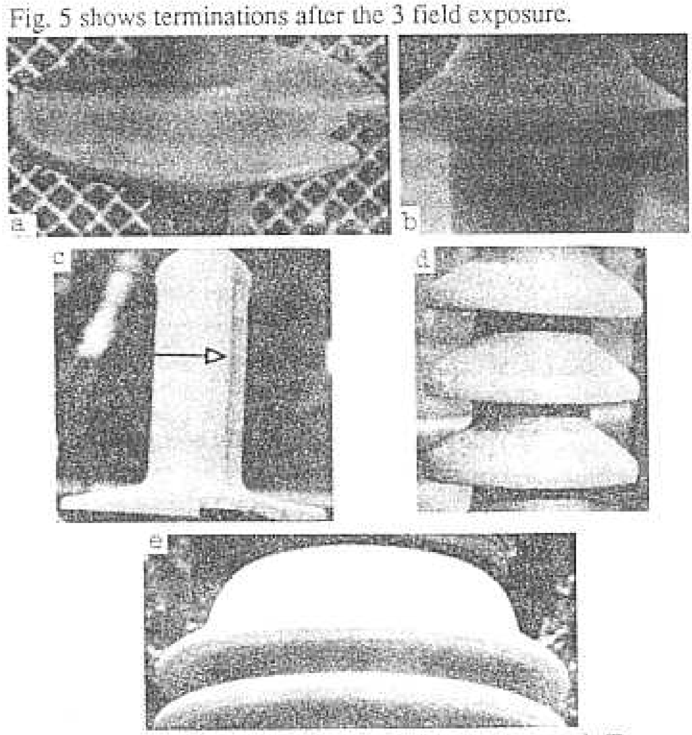

Fig. 5: (a) Partly wettable-Term. A; (b) Mold growth-Term. B, (c) Hardware weathering stain-Term. C; (d) Chalking, crazing-Term. D; (e) Relatively clean surface-Term. E.

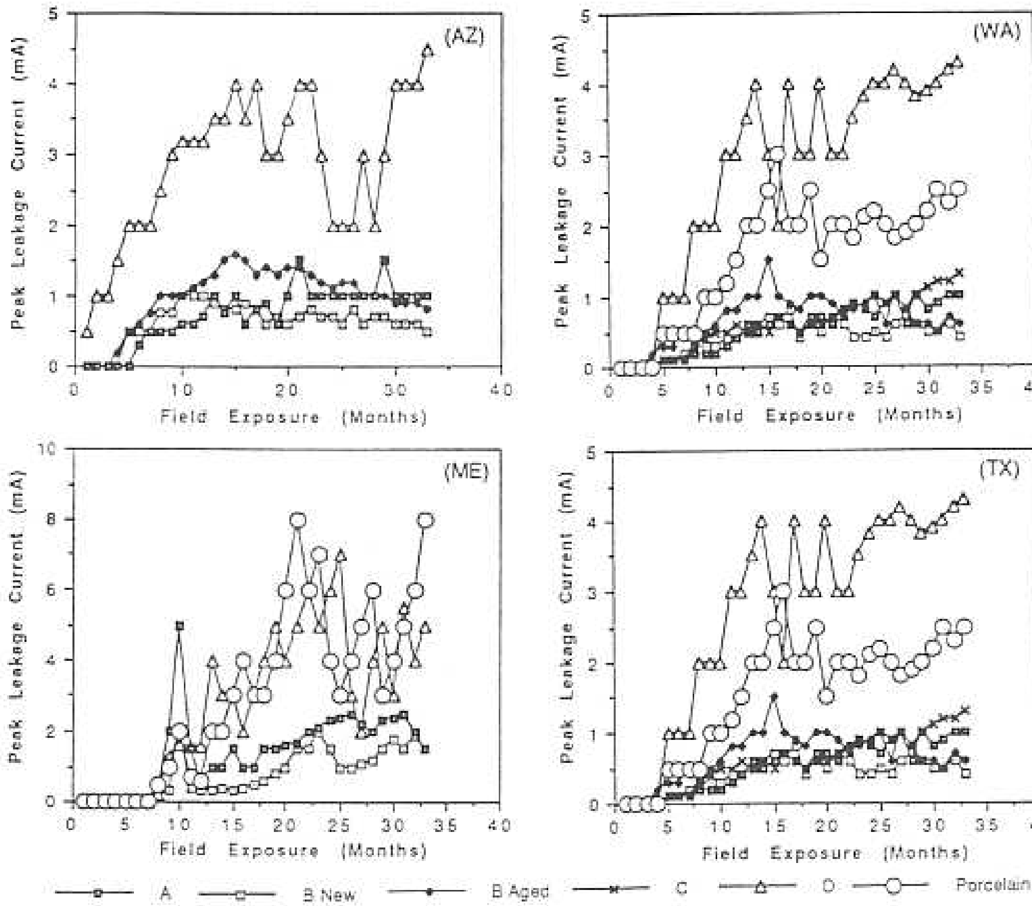

Fig. 6: Highest Peak Leakage Current by Month

5b. Leakage Current and Watt Loss

The highest peak leakage current recorded every month in four of the testing sites is shown in Fig. 6. Table 4 lists the typical leakage current pulse data from one site. There was a large volume of data from which the following important observations have been made:

Table 4: Sample Daily Output From Data Acquisition System From One Test Site showing Pulse counts in bins.

Termination	1-2 mA	2-3 mA	3-4 mA	4-5 mA	Highest Peak (mA), time
A	10	0	0	0	1, 1 AM
B	30	0	0	0	3, 5 AM
B (aged)	108	72	10	0	4, 4 AM
C	18	0	0	0	1, 3 AM
D	100	60	20	0	4, 3AM
E(Porcelain)	300	240	190	40	5, 5 AM

Note:Terminations B (aged) have been previously aged for about 10 years prior to this project.

1. There was a substantial period of > 23 hours during the day where the leakage current was < 1 mA (threshold set for detection), indicating a dry surface.
2. The number of pulses recorded daily was less than 1000 for the lowest range (1-2 mA) and decreased substantially for higher ranges, as shown in Table 4. The number of pulses corresponds to < 1 minute of continuous leakage current followed by a long period with virtually no leakage current.
3. Most of the leakage current activity was recorded during night and early morning hours, indicating condensation wetting by dew and fog.
4. Initially, the leakage current was low (< 1 mA) and increased subsequently for all samples. On porcelain and EPR D terminations, 5-10 mA range pulses were recorded. Consistently, the lowest peaks occurred on Termination A and B, and high peaks on Termination D and porcelain. Termination C's leakage current was within this range. It is interesting to note that Termination D, despite the higher leakage distance than C, had higher current. This is attributed to differences in the material formulation.

5. The Watt loss from the Georgia site, shown in Fig. 7, illustrates similar trends as leakage current from other sites. EPR D and porcelain terminations have higher watt loss than terminations A and B. However, even the highest watt loss is negligible.

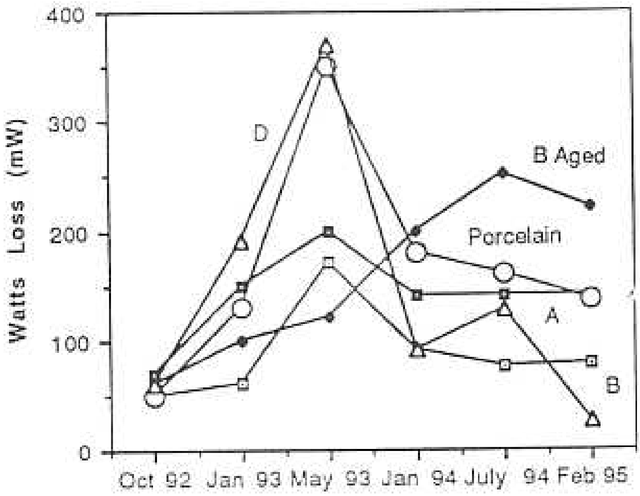

Fig. 7: Watt Loss Data from Georgia Site.

5c. Material Analyses

The materials were analyzed in their unaged condition, yearly, and after the 3 year field exposure. Fig. 8 shows the maximum COV change recorded on the different samples.

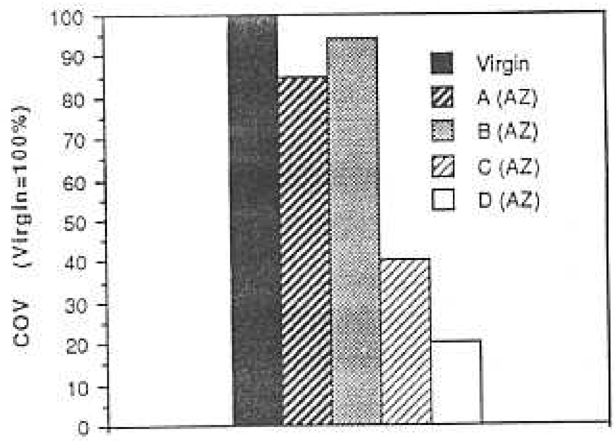

Fig. 8: Maximum COV change. COV (eV) for virgin (100%) are A=900, B=1000, C=800, D=600.

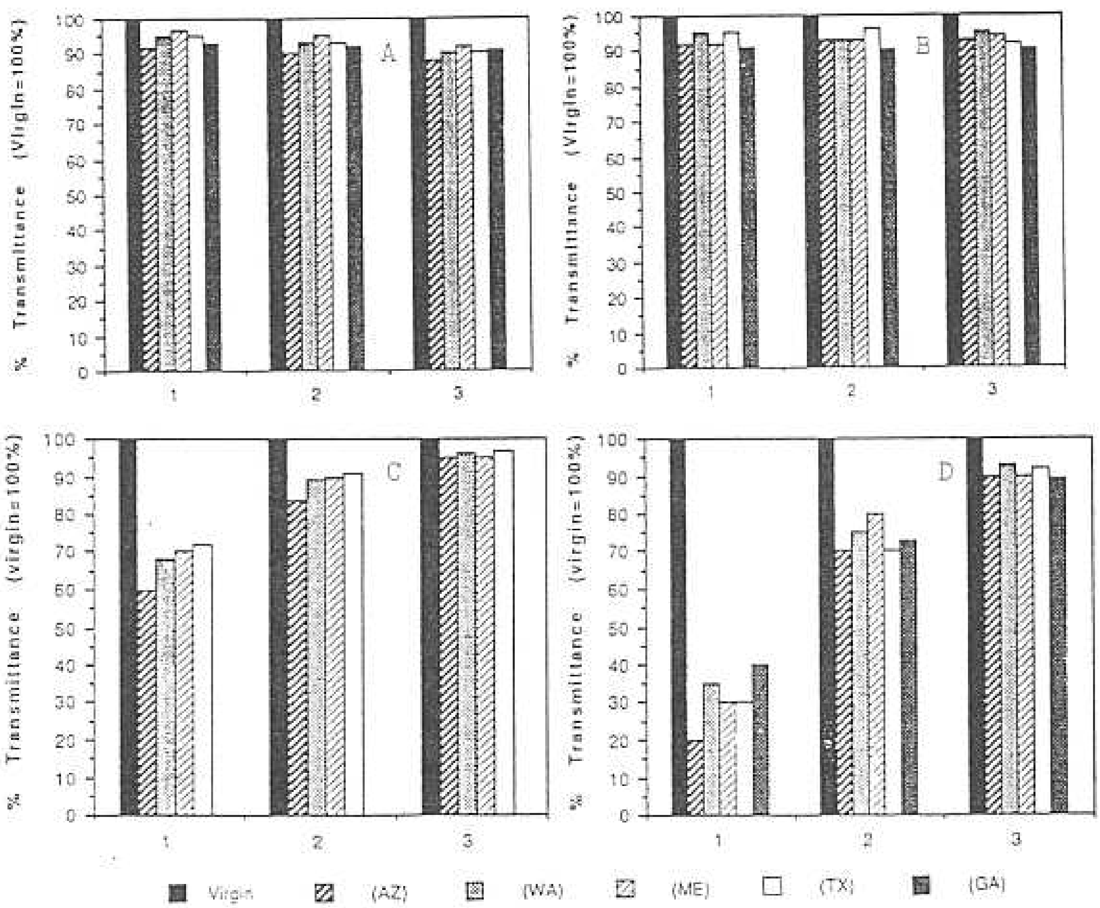

Fig. 9: IR data on Terminations before and after 3 year field exposure. Information on Groups on X-axis is shown in Table 5.

It can be seen that the complete loss in hydrophobicity of termination C and D, partial loss of hydrophobicity of termination A, almost unchanged hydrophobicity of termination B are clearly borne out by the Cross Over Voltage measurement. Interestingly, the maximum changes occurred in the Arizona site, demonstrating the dominant role of UV on surface wettability.

Fig. 9 shows the IR data. Since the polymer families evaluated are different, the peaks of IR Transmittance occur at different wavenumbers. To facilitate relative comparison, the most meaningful peaks of each material are classified by groups on the abscissa of Fig 9. The chemical functional groups for the various termination materials are listed in Table 5.

Table 5: Details and Significance of Groups Used in IR Data of Fig. 9

Term	Group	Wave number (cm^{-1})	Chemical Function	Source
A	1	2900	C-H	side chain (CH2, CH3)
	2	1750	C=C, C-O	side chain
	3	1000	C-C	backbone
B	1	2950	C-H	side chain (CH3)
	2	1260	Si-CH	side chain (Si-CH3)
	3	1050	Si-O	backbone
C	1	2900	C-H	side chain
	2	1500	C-H, C-O	side chain
	3	1000	C-C	backbone
D	1	2900	C-H	side chain
	2	1500	C-H, C-O	side chain
	3	1000	C-C	backbone

The peak at 3600 cm^{-1} (not shown in Fig. 9) corresponding to the hydrated filler was found to increase with reference to the virgin data, after field exposure for terminations C and D. The maximum increase was in the Arizona site where for Termination C, the increase was about 30% and for D about 100%. For termination D, the increase is due to chalking that is apparent. This indicates depletion of the top polymer monolayers which initially cover the ATH filler, leaving more exposed filler on the surface. At this wavenumber there were insignificant change from the virgin for terminations A and B.

Fig. 9 shows the relative transmittance peaks corresponding to chemical groups in the polymer side chain and backbone. The magnitude of the peaks for the virgin samples is normalized to 100%. All these peaks decreased with field exposure. For all polymers, the decrease for the side chain group was more noticeable than the backbone. In fact, the change in the backbone peak was negligible for all samples, indicating that the integrity of the material after field exposure is still unchanged from the virgin condition. Decrease in the transmittance peaks of side chain, reflecting wettability changes, were more noticeable for terminations C and D, being higher for D. For terminations A and B, even the superficial changes are minimal, being least for Termination B.

6. CONCLUSIONS

The conclusions listed in this section pertain to the terminations evaluated in the sites selected for this project:

1. Installation of terminations in various test sites proved to beneficial for understanding the magnitude of aging produced changes owing to field exposure.
2. Leakage current on all terminations evaluated was low, and can be attributed to both material nature and design.
3. Leakage current activity on all terminations was sparse, with no activity for most of the day. The low level and sparsity of leakage current activity in field sites located in harsh conditions is encouraging, as it indicates that these types of terminations could be expected to perform satisfactorily in most outdoor locations.
4. The minor chemical changes observed on all polymeric terminations could be possibly due to weathering than due to surface discharge activity.
5. The magnitude of the chemical changes observed was small and only superficial. It is therefore unlikely that failure of any type of the terminations evaluated could have occurred even in a much longer time frame. This will be substantiated further in the accompanying paper.

7. REFERENCES

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