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Material Testing Research and Indenter Equipment Modifications for Determining Aging of Wires (Cables) in Aircraft

October 2004

Final Report

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16. Abstract

The objective of this research study was to validate the Indenter Polymer Aging Monitor (Indenter), originally develop by The Electric Power Research Institute in the 1980s for use in utility nuclear power plants, as a means of characterizing aircraft wire degradation by means of monitoring the properties of the wire insulation. The Indenter is a portable, simple-to-operate, nondestructive instrument for gathering data, which could be used as a test method that monitors the aging of wires and cables by measuring the changes in compressive modulus. The data and analysis in this report demonstrates that insulation hardness measurements obtained with the Indenter can be correlated with accepted destructive methods such as elongation-at-break and Wire Insulation Deterioration Analysis System to provide a relative measure of wire insulation degradation.

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Robert Pappas	Federal Aviation Administration
Armin Bruning	Lectromechanical Design Company
William G. Linzey	Lectromechanical Design Company
David Allen	Consultant to DuPont Co.
Owen Greulich	NASA Ames Research Center
Eddie White	Wright-Patterson Air Force Base

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LIST OF ACRONYMS

AC	Alternating current
CCA	Cable clamp assembly
DAU	Data acquisition unit
DC	direct current
EAB	Elongation-at-break
EPRI	Electric Power Research Institute
ETFE	Ethylene-tetrafluoroethylene copolymer
FEP	Fluorinated ethylene
FP	Fluorocarbon polymer
IPAM3	Indenter polymer aging monitoring model 3
LED	Light emitting diode
LVDT	Linear variable differential transformer
NIST	National Institute of Standards and Technology
PC	Personal computer
PTFE	Polytetrafluorethylene
PVC	Polyvinyl chloride
rms	Root mean square
TKT	Teflon®-Kapton®-Teflon®
WIDAS	Wire insulation deterioration analysis system

EXECUTIVE SUMMARY

The Electric Power Research Institute (EPRI) originally developed the Indenter in the 1980s for use in utility nuclear power plants. The Indenter is a nondestructive test method that monitors the aging of wire and cable insulation by measuring changes in compressive modulus. As wire ages, significant changes in this mechanical property precede changes to the electrical insulation capability. Aging wires cause embrittlement and cracking, which may result in significant electrical malfunctions and dangerous conditions such as electrical arcing.

The objective of this research is to demonstrate to the reader that data obtained by testing aircraft wire insulation with the Indenter Polymer Aging Monitor (Indenter) can be correlated with the aging of the wire insulation or cables. Activities included in this research study were: modification of the Indenter design to enhance its capabilities to test small wires, standardized test procedures for using the modified Indenter, accelerated thermal aging of various insulation test specimens, and the evaluation of the effects of accelerated aging on the insulation systems by comparing Indenter Modulus, Elongation-at-Break (EAB), and Wire Insulation Deterioration Analysis System (WIDAS) tests.

Changes in mechanical properties are typically evaluated by EAB testing. However, EAB testing is destructive and requires relatively large specimens, making it undesirable for analyzing installed cables. As an alternative to EAB tests, Indenter tests that measure compressive modulus provide a systematic indication of material aging. Thus, Indenter data obtained during testing that also obtained EAB (or other) data at the same level of aging can be combined in a graph to predict remaining cable life. New Indenter data obtained from wires installed in aircraft can be compared to the graph to estimate the wire life. Six type of common aircraft wires, Polyvinyl Chloride (PVC), PVC/glass/nylon (PVC G-N), XL-ETFE (Cross-linked Tefzel), Composite TKT (Teflon®-Kapton®-Teflon®), Polyimide (Kapton®) #20 AWG Instrument cable, and Polyimide (Kapton®) #10 AWG Power cable, were subjected to testing. Wire specimens were subjected to accelerated thermal aging in ovens prior to performing any EAB, Indenter, or WIDAS tests. The thermal aging program was based on two factors, maximum aging time of 12 weeks and an aging temperature that was 20°C higher than the maximum temperature rating of each wire type.

This research study illustrates that after testing of the various aged wire specimens with the indenter, the accuracy of the data obtained by Indenter is not dependent on the experience of the person performing the test, and it is suitable for testing small wires installed in aircraft. Results from the indenter correlate well with EAB and WIDAS test results, but the type of material of the different insulation specimens has an important role on this correlation. The general shape (convex/concave) of the curves fitted to the data plots for Indenter modulus and relaxation values are typically the same, and the application of relaxation data to material aging as a recommendation must be evaluated further. Finally, data for some aged materials fell within the assumed accuracy of the Indenter and showed no trends. These were materials for which there is no comparison data available from other testing methods. Since the amount of aging degradation, resulting from the aging protocol is unknown, it cannot be determined if the Indenter results indicate that the material actually was not aged significantly or if the Indenter measurements are not suitable for that type of material.

1. INTRODUCTION.

The objective of this research was to demonstrate that modulus readings obtained by testing aircraft wire with the Indenter Polymer Aging Monitor could be correlated to the aging of wire or cables. Additional research was done to improve the consistency of the indenting method and data and assemble age-related information from other sources.

Specific activities included were as follows:

- Design modification of the Indenter to enhance its capabilities to test small wires
- Development of a standardized test procedure for using the modified Indenter
- Accelerated thermal aging of various insulation systems currently used in aircraft
- Evaluation of the effects of accelerated aging on the insulation systems by performing Indenter modulus, elongation-at-break (EAB), and wire insulation deterioration analysis system (WIDAS) tests.

The accelerated thermal-aging exposures and EAB tests were performed at the Engineering Research and Development facility of the Boeing Company in Everett, WA. The WIDAS tests were performed at Lectromechanical Design Company in Dulles, Virginia. The Indenter tests were performed at Analog Interfaces, Inc.

The Indenter Polymer Aging Monitor (Indenter) was originally developed in the 1980s for use in utility nuclear power plants. The development was funded by the Electric Power Research Institute (EPRI) as part of a research program to produce a nondestructive test method that could monitor and evaluate the aging of insulation materials of electrical cables. The Indenter measures the changes in compressive modulus of the insulation materials. When low-voltage cable ages, significant changes in this mechanical property precede changes in electrical insulation capability.

Changes in mechanical properties of insulation and materials typically have been evaluated by means of EAB testing. However, EAB testing is destructive and requires relatively large specimens, making it undesirable for analyzing installed cables. As an alternative to EAB tests, EPRI performed tests to evaluate compression, relaxation, creep, and recovery properties. The research showed that the change in force divided by change in position of a probe pressing at a constant velocity against the insulation of a cable provided a systematic indication of material aging. For materials that harden as they age, the measured compressive modulus also increases. Thus, Indenter data obtained during testing that also obtained EAB (or other) data at the same level of aging can be combined in a graph to predict remaining cable life. New Indenter data obtained from wires installed in aircraft can be compared to the graph to estimate the wire life.

2. SELECTION OF TEST MATERIALS AND THERMAL-AGING EXPOSURES.

2.1 TEST MATERIALS.

This research included tests of six types of insulation materials. A variety of wire types and constructions were selected because they are commonly used on the aircraft industry. The final list of cable types was developed after extensive input from industry experts. All wires were size #20 AWG except for the power cable that was #10 AWG. The total thickness of the various insulation systems was approximately the same. The following is a description of the wires:

- Polyvinyl Chloride (PVC) MIL-DTL-16878/1C
  The conductor is covered with extruded PVC insulation 8 to 11.5 mils thick.

- PVC/glass/nylon MIL-W-5086/2C
  The conductor is covered with extruded PVC insulation that is covered by glass fiber braid, which is covered by extruded 6-mils-thick clear nylon. The combined thickness of the PVC and braid is 18 mils. The PVC insulation thickness is assumed to be 8 to 11.5 mils.

- XL-ETFE (Cross-linked Tefzel) MIL-W-22759/42B
  The conductor is covered with two extrusions. The first extrusion is 3 mils (min.) of cross-linked modified ethylene-tetrafluoroethylene copolymer (ETFE). The second extrusion is 4 mils (min.) of cross-linked modified ETFE. The total combined insulation system must be 8 mils (min.) thick.

- Composite TKT (Teflon®-Kapton®-Teflon®) MIL-DTL-22759/90A
  The conductor is covered with two wrapped tapes; the overlap for each wrapping is 50% (min). The first wrap over the conductor consists of 0.5 mil of fluorocarbon polymer (FP), modified polytetrafluoroethylene (PTFE), over 1 mil of polyimide covered by 0.5 mil of FP. The second wrap consists of 2 mil of FP. The nominal thickness of the entire insulation system is 7.4 mils.

- Polyimide (Kapton®) #20 AWG Instrument cable MIL-W-81381/12C
  The conductor is covered with two wrapped tapes; the overlap for each wrapping is 50% (min). The first wrap over the conductor consists of 2 mil of polyimide film covered by 0.5-mil fluorinated ethylene propylene (FEP) fluorocarbon resin. The second wrap consists of 0.1-mil FEP fluorocarbon resin over 1 mil of polyimide film that is covered by 0.1 mil of FEP fluorocarbon resin. The second wrap is then coated with 0.5 mil of aromatic polyimide resin. Approximate thickness of the entire insulation system is 8 mils.

- Polyimide (Kapton®) #10 AWG Power cable MIL-DTL-22759/86A
  The conductor is covered with two wrapped tapes; the overlap for each wrapping is 50% (min). The first wrap over the conductor consists of 0.5-mil FP over 1 mil of polyimide over 0.5-mil FP. The second wrap consists of PTFE (unsintered). Nominal wall thickness of the entire insulation system is 9.5 mils.

2.2 WIRE NAMING TERMINOLOGY.

The wires used in this research were referred to differently in various documents and by the various personnel involved as the research developed. Thus, for the purposes of testing tabulation, the following wire descriptions have been used: PVC, PVC G-N, XL-ETFE, Composite TKT, Polyimide INST, and Polyimide Power. All the wire test specimens and the storage bags containing the test specimens were labeled using these descriptions.

The term polyimide power cable can be misleading since the primary insulation is Kapton®. The inclusion of the other materials actually results in the total insulation system being identical to that described as Composite TKT. The original intent was to include a power cable whose total insulation system was identical to the Kapton® that was used on the instrument wire (#20 AWG). However, as the aging part of the research began, it was determined that such a wire was not readily available. Thus, another type of power cable was substituted. Analog Interfaces, Inc. did not become aware that the substituted insulation system was identical to the Composite TKT insulation system until much later in the research. Therefore, the original nomenclature of Polyimide Power was retained.

2.3 ACCELERATED THERMAL-AGING EXPOSURES.

Table 2-1 shows the aging temperature, weeks of aging, and sampling rate for the six wire types.

TABLE 2-1. THERMAL-AGING TEMPERATURES, DURATIONS, AND SAMPLING RATES

Insulation System	Aging Temp.	Weeks of Aging	Sampling Rate
PVC	125°C	8	Remove 10 samples every two weeks
PVC/glass/nylon	125°C	8	Remove 10 samples every two weeks
XL-ETFE (Cross-linked Tefzel®)	220°C	12	Remove 10 samples every three weeks
Composite (Teflon®-Kapton®-Teflon®)	280°C	12	Remove 10 samples every three weeks
Polyimide (Kapton®) (instrument wire)	220°C	12	Remove 10 samples every three weeks
Polyimide (Kapton®) (#10 AWG power)	220°C	12	Remove 10 samples every three weeks

The original intent of the thermal-aging program was to age all specimens in a consistent manner such that they all were at a defined end-of-life status at the conclusion of the accelerated aging exposure. However, the requirements for aging ovens and durations exceeded the scope of resources available. Consequently, the revised version of the aging program was based on the following two factors: (1) a maximum aging time of 12 weeks and (2) an aging temperature that was 20°C higher than the maximum temperature rating of each wire type. Each organic material ages at a rate that is dependent on the activation energy (eV) specific to that material. However, there is a very general rule of thumb which states that the thermal life of a material decreases by one-half for 10°C increase in temperature. Thus, if a theoretical material normally reached its end of life in 10,000 hours when operated at 105°C, then a 10°C increase would reduce the total operating life by one-half to 5000 hours. For example, the rating for the simple PVC wire was 105°C; therefore, 20°C was added to that value to obtain an aging temperature of 125°C. This method does not produce a known endpoint at the conclusion of the aging exposure, but it does ensure that some measurable aging occurs by the end of the 8- or 12-week aging period. In this report, aging levels are referred to by the letter A followed by the number of weeks that the specimen was aged, i.e., A0 (unaged), A2, A3, A4, A6, A8, A9, and A12.

Given the length of the test wires and available space in the ovens, personnel found it necessary to droop the test wires over a rod, rather than to hang a straight specimen in air. This method is accepted in industry practice, and sometimes a weight is hung from each end of the wire. However, no weights were used in this program.

3. ELONGATION-AT-BREAK TESTING.

The original test plan anticipated that EAB testing could be performed on three of the six wire types, namely, PVC, PVC G-N, and XL-ETFE. The wrapped nature of polyimide insulation and the complexity of the Composite TKT insulation precludes obtaining meaningful data from EAB testing of these materials. However, it was subsequently determined that EAB testing on PVC G-N was not feasible as well. All EAB testing was performed by Boeing, the original data provided by Boeing is presented in appendix C. (Boeing refers to EAB as elongation at rupture.)

3.1 ELONGATION-AT-BREAK METHODOLOGY.

EAB testing consists of removing the metallic conductor so that only the insulation remains. The insulation piece is then placed between two clamp jaws and stretched at a constant speed until the insulation breaks. A variety of data is recorded, such as, the breaking force of the specimen, the distance between benchmarks at rupture, and cross-sectional area (columns C, F, and L_2 on test data table in appendix C). The data is used to calculate EAB (%) and show the percent that the material stretches before breaking decreases as the material ages.

Boeing calculated EAB values using two different methods (columns 9 and 10 in appendix C):

- Elongation at rupture by Instron (%) (method typically used in the cable industry)
- Elongation per BSS 7324 by scale (%) (Boeing standard test method)

Both calculations use the same raw data taken from the test samples.

3.2 NUMBER OF DATA POINTS.

Since only one EAB test can be done on a given sample, with ten samples at each aging level, the Boeing data consists of a maximum of ten values for each aging level. In some cases, due to testing problems, less than ten data points are available.

3.3 ELONGATION-AT-BREAK TEST RESULTS.

The EAB data from appendix C, shown in figures 3-1 and 3-2, have been plotted with curve fits and a vertical bar for 0.95 confidence levels. Figure 3-1 shows what appears to be an anomaly in the data at the 6-week aging level. The 0.95 confidence level shows data variation of around $\pm$6% Figure 3-2 shows a good curve fit to the data. The 0.95 confidence level shows data variation to be small. A 95% confidence interval for an unknown quantity such as average value may be characterized as follows: If one repeatedly calculates such intervals from many independent random samples, 95% of the intervals would, in the long run, correctly bracket the true average value. More commonly, but less precisely, a two-sided confidence interval can be described as follows: there is a 95% confidence that the interval lower limit to upper limit contains the unknown true value of the average.

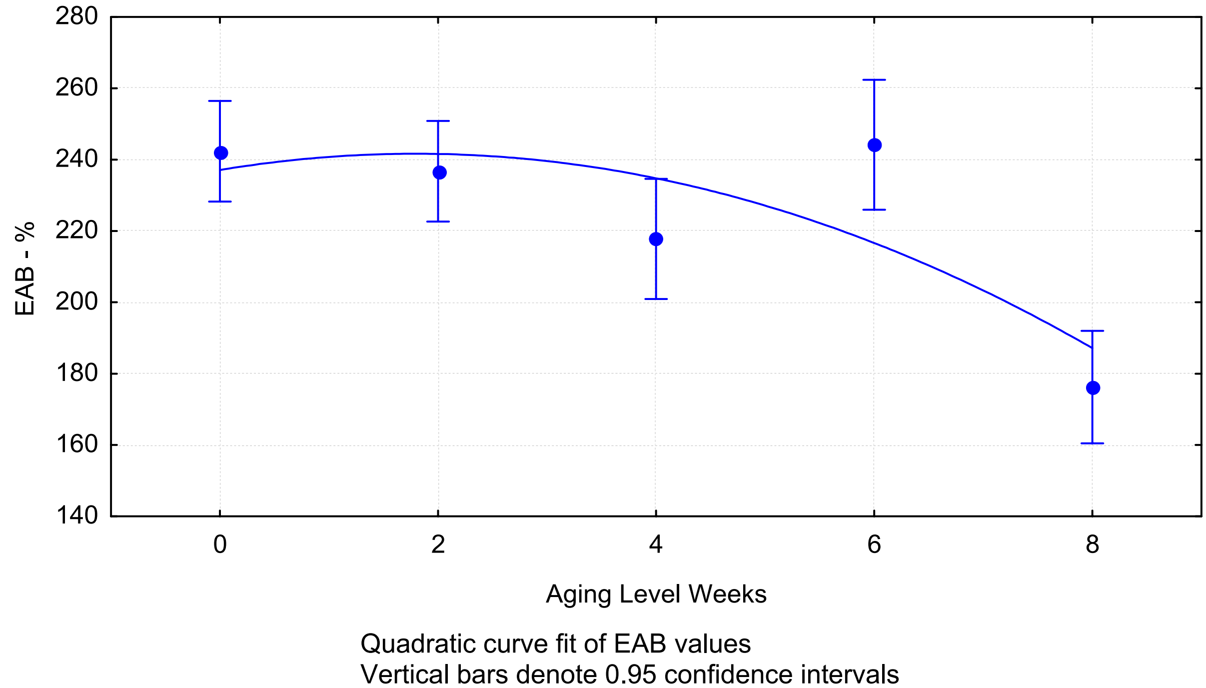


FIGURE 3-1. ELONGATION-AT-BREAK VERSUS AGING LEVELS FOR PVC

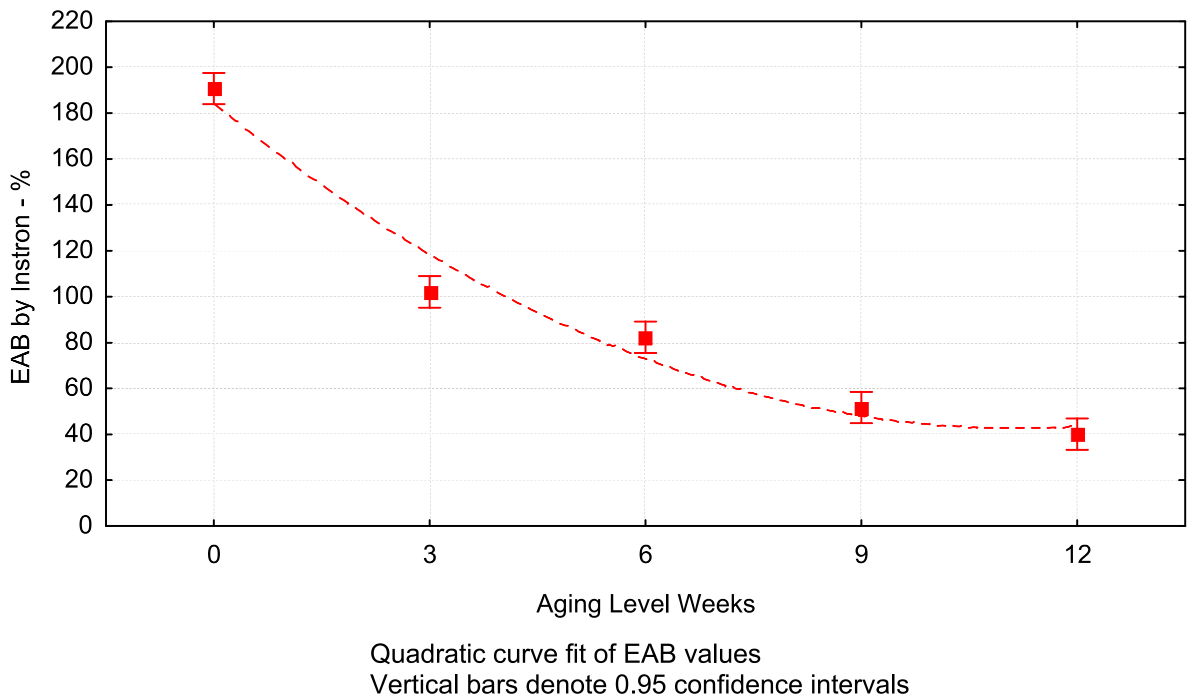


FIGURE 3-2. ELONGATION-AT-BREAK VERSUS AGING LEVELS FOR XL-ETFE

4. INDENTER TESTING PROCEDURES.

This section describes how the test samples were prepared and labeled, the Indenter tests were taken, the data was reviewed, test exclusion decisions were made, and the data was formatted into a spreadsheet for statistical analysis.

4.1 PREPARATION OF WIRE SAMPLES.

The aged wire samples were received from Boeing in six large plastic bags, each contained the wires for one of the six types of wires in the test program. Within the large outer bag were separate bags containing specimens from each aging level. Each wire was labeled by attaching a tag with the following information:

- Wire type—Used the designations listed in section 2.2

- Aging level—For PVC and PVC G-N, the aging level designations were A0, A2, A4, A6, and A8. For the other four wire types the aging level designations were A0, A3, A6, A9, and A12.

- Sample Number—A sample number from 1 to 10 was randomly assigned to each aged wire sample furnished by Boeing. Boeing had not labeled each sample, therefore, specific pieces of wire could not be correlated with their EAB test results.

Although it was not originally intended to make correlations among the various wire samples from the same aging level, it was decided to label them for future reference. Thus, all the modulus and relaxation values taken are identified with a specific wire number.

The labeling method is illustrated in figure 4-1; that is, PVC A0 #2 indicates that this is a PVC type wire, unaged, and is wire #2 out of the 10 wires furnished by Boeing. This method of labeling was also applied to other test specimens received from Lectromec Design Company, even though Lectromec had already attached their own labels using a Lectromec identification system, as shown in figure 4-2.

FIGURE 4-1. WIRE SAMPLE LABEL

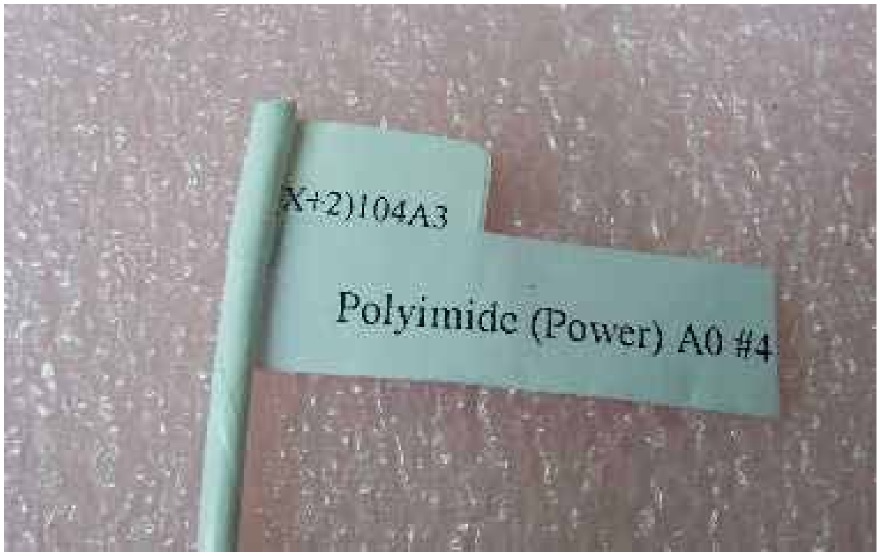


FIGURE 4-2. EXAMPLE OF LECTROMEC TEST, SAMPLE LABELING (X+2)104A3 WITH ANALOG INTERFACES LABEL ADDED

4.2 LENGTH OF TEST SPECIMENS.

Each test specimen prepared by Boeing for accelerated thermal aging was approximately 24 inches in length. Some of the specimens received for Indenter modulus testing were shorter because part of the aged specimens were removed for either EAB or WIDAS testing. Table 4-1 shows the specimen lengths.

TABLE 4-1. SPECIMEN LENGTHS FOR ALL TESTS

Wire Type	Length During Thermal Aging	Length for Indenter Tests	Comment
PVC	24 inches	16 inches	8 inches used for Boeing EAB test
PVC G-N	24 inches	16 inches	8 inches used for Boeing EAB test
XL-ETFE	24 inches	24 inches	- - -
COMPOSITE TKT	24 inches	24 inches	- - -
POLYIMIDE INST	24 inches	6 inches	18 inches used for Lectromec WIDAS test
POLYIMIDE POWER	24 inches	6 inches	18 inches used for Lectromec WIDAS test

4.3 TESTING PROCEDURE.

The testing procedure (see appendix B) was performed by three testers. Each specimen subjected to Indenter testing was tested independently at different times by all three testers. Each tester began with the unaged samples (A0) and then proceeded through the other four aging levels.

Ten wire samples from each aging level were available for Indenter testing; however, only five samples of each kind were tested. The reasons for this were:

- First, since all the wire samples initially came from the same spool and all were exposed to the same conditions during accelerated thermal aging, any location on any of the ten wires was considered equally representative of the aging characteristic of the wire. Thus, testing ten locations on five wires should be equivalent to testing five locations on ten wires.

- Second, testing all ten samples would double the length of testing time without any foreseen benefit. Statistical analysis of the data was performed, which showed that obtaining 50 data points for each aging level (five wires tested times ten tests per wire) times three testers for a total of 150 data points would be enough data points for a good statistical analysis.

The Indenter software permits up to ten individual tests in one test session. For this research, a test session was defined as ten tests along the length of wire being tested.

4.4 TEST EQUIPMENT AND METHODOLOGY.

4.4.1 Hardware.

Figure 4-3 shows the entire Indenter system ready to perform modulus testing. The system consists of the following:

1. Cable clamp assembly (CCA) in which the wire is inserted for testing
2. Data acquisition hardware
3. Interface box
4. Cable connecting the interface box to the data acquisition system

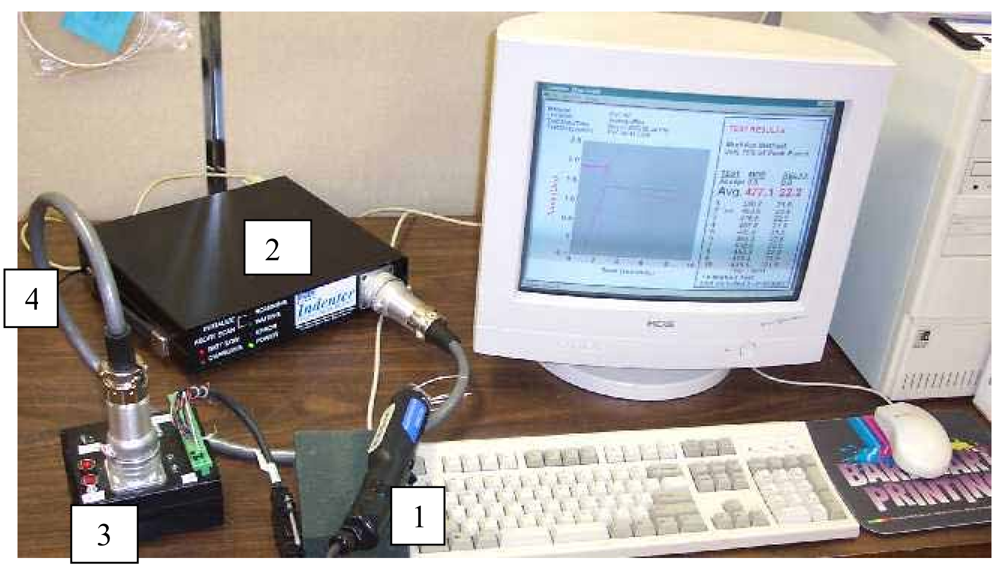


FIGURE 4-3. SYSTEM SETUP FOR INDENTER TESTING

The test equipment setup used for this research was not the new portable system that was developed as part of the overall research because the new hardware and software was not completed when the accelerated aging tests were finished. However, the CCA assembly that was used contains the identical internal mechanism that is present on the new system. Thus, the data taken in this test will be the same as if it was taken with the new portable version.

4.4.2 Software.

The software used for this research was the current Indenter system software, which was also used as the host or office personal computer (PC) software for the new portable system. Examples of the various software testing screens are presented in section 4.4.3.

4.4.3 Methodology.

The tester removes the first five samples for each aging level from the storage bag and inputs the information into the computer, consisting of material type, aging level, sample number, and tester name (PVC, A3, #1, Dave).

Starting with the sample labeled 1, the tester prepares the wire for testing by pulling back on a trigger on the CCA to open the jaw clamp, inserting the wire, and then releasing the trigger (which holds the wire firmly in place). The tester presses the SCAN button on the interface box, and the probe starts moving toward the wire. When it contacts the wire, data measurements of force and displacement (probe movement) are taken at 100 samples per second. When the force reads 2 pounds, it stops moving.

During a standard modulus test, the probe immediately retracts when the force reads 2 pounds. In this research, however, a second variable called the relaxation value was also being determined (force data is recorded while the probe is held at the deformation achieved when the force value initially reached 2 pounds). Obtaining relaxation data takes about 7 seconds and then the probe retracts. The computer screen displays the modulus and relaxation values just obtained, and the system is automatically set to take the next data point.

The tester opens the clamp jaw and moves the wire to a new location, which is randomly selected and not marked in any way. The tester rotates the wire so that all testing is not done on the same side and moves the wire a distance so that all ten tests can be made along the whole length of the wire. When the ten tests have been completed, the test session is done. Figures 4-4 to 4-7 show the test methodology steps.

FIGURE 4-4. REMOVING WIRE SAMPLES

FIGURE 4-5. PERFORMING A TEST ON POLYIMIDE POWER WIRE

FIGURE 4-6. CABLE CLAMP ASSEMBLY, TOP VIEW

FIGURE 4-7. CABLE CLAMP ASSEMBLY, SIDE VIEW

4.4.4 Testers.

Three testers performed indenter modulus testing. One tester had 15 years of experience with the Indenter. The other two testers had no experience. While one of the testers had some technical education, the other did not. The three testers were specially chosen to perform the Indenter tests to determine if the test results were dependent on the experience of the user.

4.5 VISUAL REVIEW OF DATA.

The test session data were reviewed on the computer screen to determine if any test anomalies had occurred. Some data was excluded because it would affect the results without representing true material changes. Other data was excluded based on experience reviewing Indenter results. The excluded data is documented and summarized in appendix D. The following is an overview of the displayed data and the decision process used to exclude data points.

Figures 4-8 and 4-9 show the graphical display of data in the Indenter software. All ten tests in the test session are displayed, as well as the test session date and time and all the individual modulus and relaxation values. These figures also show the average of the individual modulus and relaxation values for that test session. This average number normally would be used in field testing to characterize a given wire. For the analysis of this research, all of the individual test points were used rather than the average value because all data points on all wire samples from the same wire type at a given aging level are equally representative of the condition of the material and are equally important in a statistical analysis. The data is displayed in two different formats:

- Force (or deformation) versus time (see figure 4-8)
- Cross plot of force versus deformation (see figure 4-9)

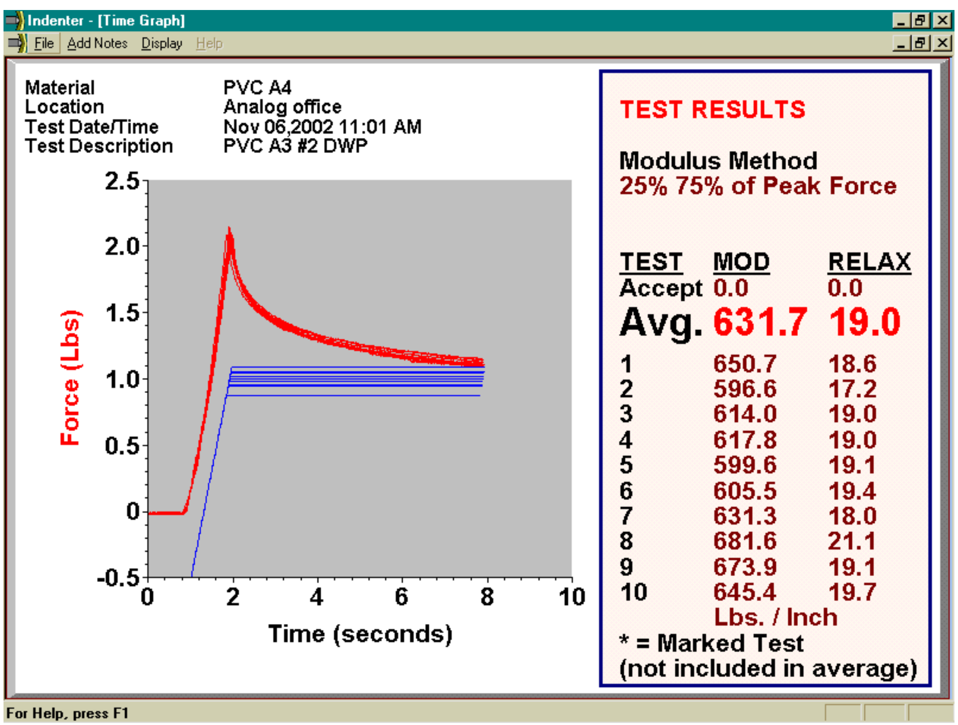


FIGURE 4-8. RELAXATION VALUE DATA SOURCE
(Force vs time – overlay of 10 tests – good repeatability)

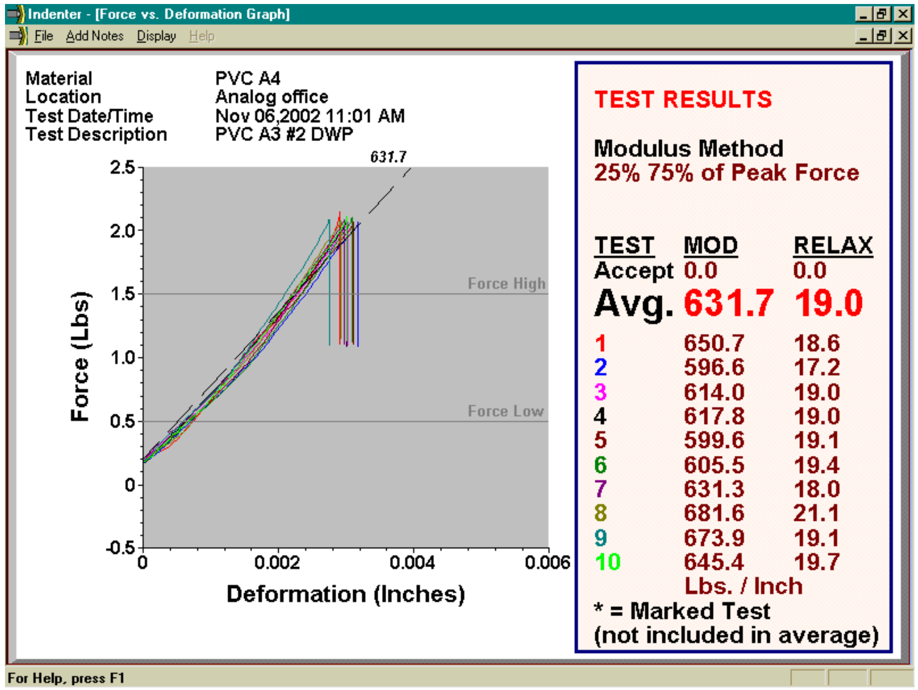


FIGURE 4-9. MODULUS VALUE DATA SOURCE
(Cross plot – force vs deformation – overlay of 10 tests – good repeatability)

The software also provided the ability to overlay all ten traces on the same plot. Thus, it was easy to review the data quickly for anomalies using the following two-step process:

1. Force versus Time. This display showed the data on which the relaxation value is calculated; the graph should be a smooth, non-linear curve. Figure 4-8 clearly shows the decay of the force after the max force is reached. Each test was quickly reviewed in this format, after which the overlay feature was used to examine all ten tests for similarity. Figure 4-8 shows a good alignment of the ten tests. In contrast, figure 4-10 shows a test where the curve is not typical. Figure 4-11 shows the overlay of ten plots that includes the test in figure 4-10 and demonstrates how the one abnormal test stands out in this overlay mode. The reason that more relaxation values were excluded than modulus values is that in most cases it was obvious (that is, not a judgment call) that something was wrong with a given relaxation test (figure 4-10). Looking at the data, it appears that a tester released the pressure on the wire by pulling on the trigger before the full test was concluded. When questioned on this, the initial tester was not aware that anything was done incorrectly. In one instance, where it was observed (during data analysis) that a large number of relaxation values were being excluded, the tester was asked to rerun the tests (after a discussion of the possible problem), and the number of rejected tests was greatly reduced. The testing manual will address this problem and show illustrations of a rejected test. The testing instructions would explain what the operator should be looking for to determine when a test has been successfully completed. Finally, if necessary, an inclusion of some sort of software alarm could be initiated to flag when a test has been completed. For modulus readings, individual tests rarely stood out as being outside the grouping of the other, leading to a fewer number of modulus readings being excluded.

2. Force versus Deformation. This display showed the data that is used to obtain the modulus reading, which is the slope of a straight line drawn between the point shown as modulus high and modulus low. Figure 4-9 shows this cross plot and is also an example of a good overlay. In contrast, figure 4-12 shows an example of one modulus test that is significantly outside the rest of the traces; thus, it was excluded from further analysis. Figure 4-13 shows an example of where the spread among the ten tests is rather wide but no one test appears to be invalid. Thus, all ten tests were used.

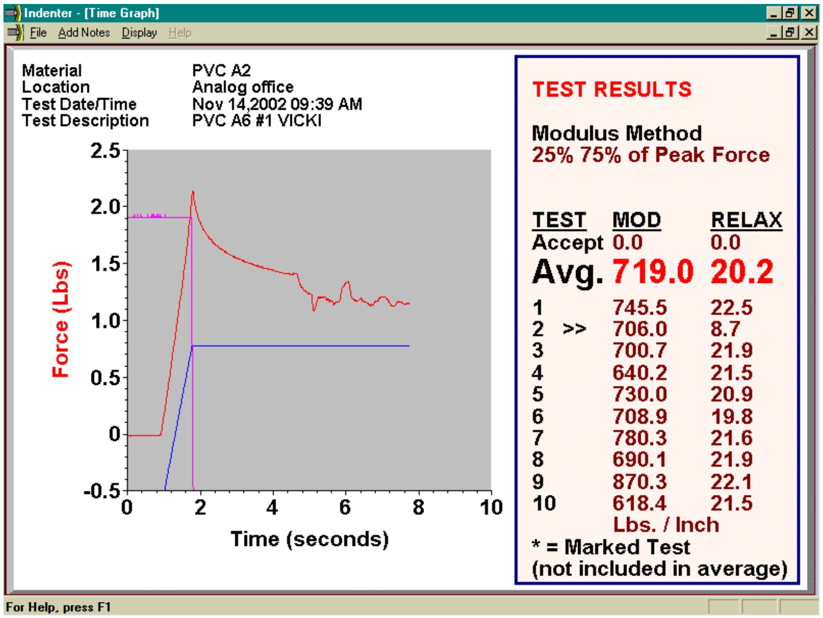


FIGURE 4-10. EXAMPLE OF EXCLUDED RELAXATION TEST

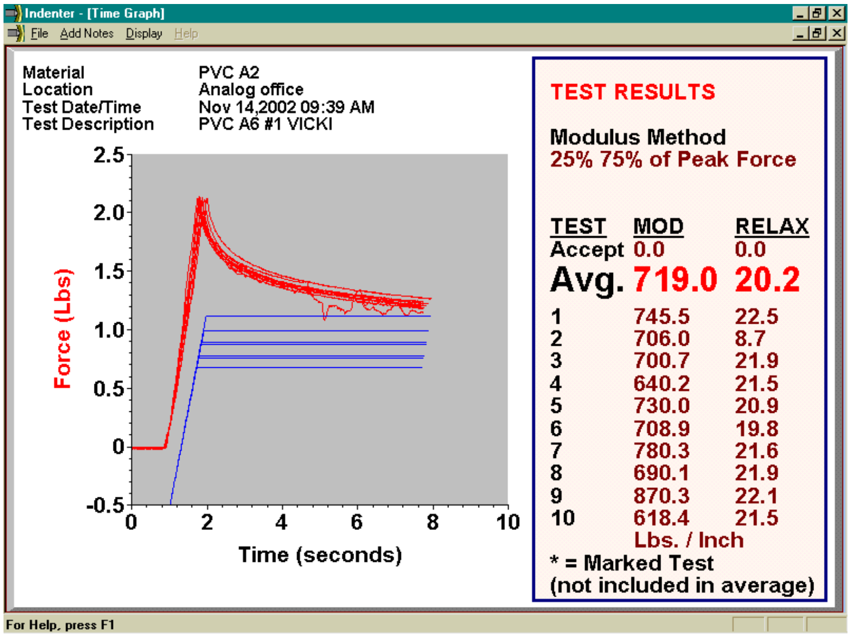


FIGURE 4-11. ONE EXCLUDED TEST REVEALED IN OVERLAY MODE

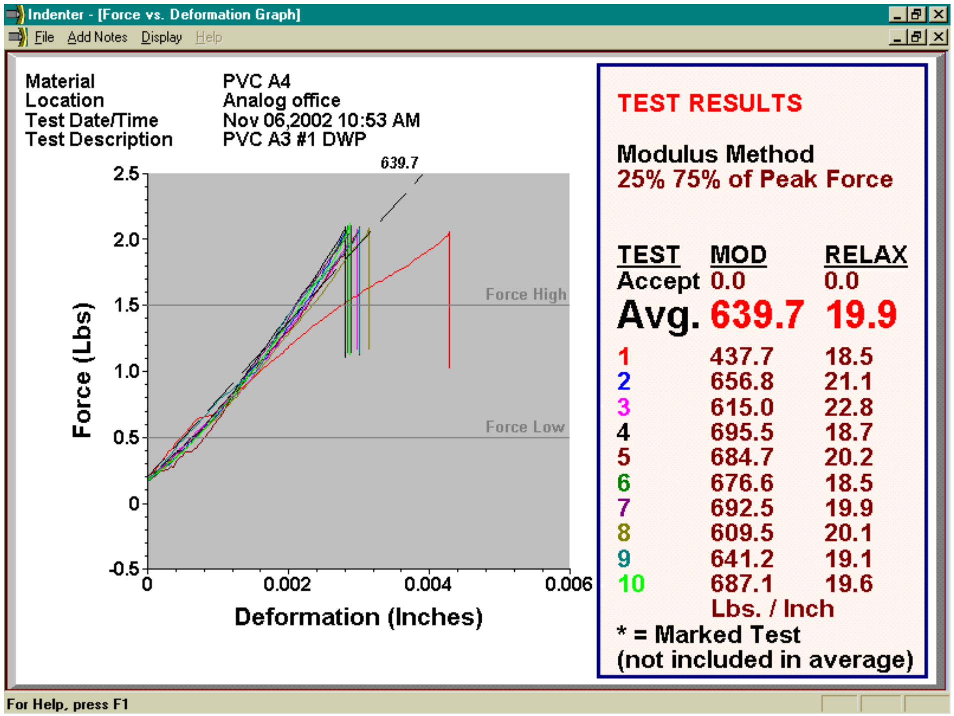


FIGURE 4-12. QUESTIONABLE MODULUS TEST—TEST 1

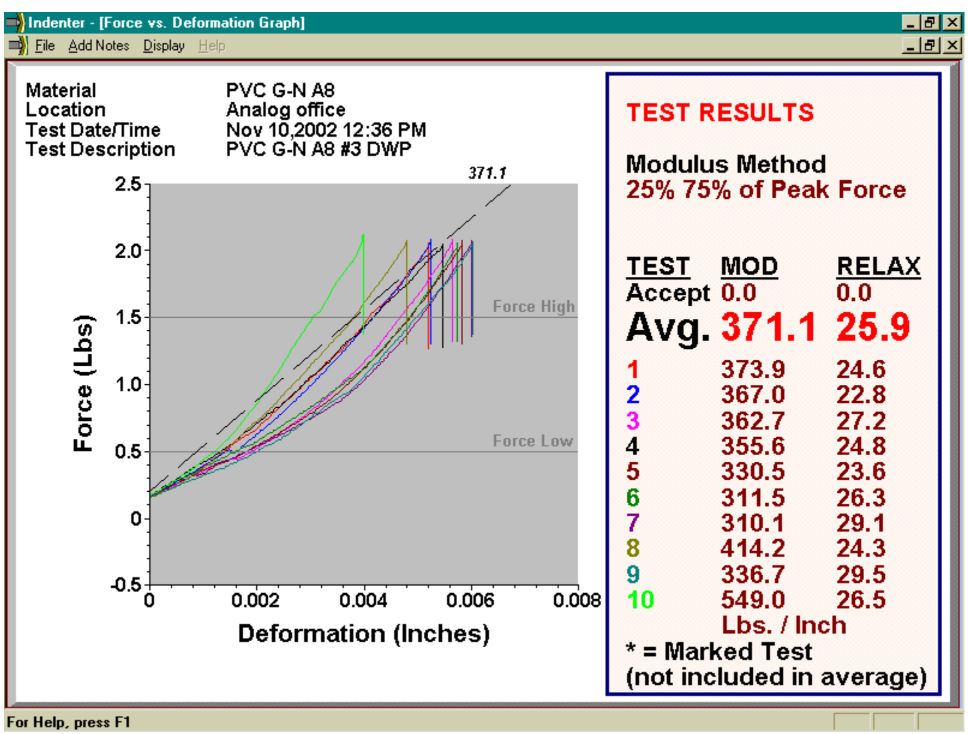


FIGURE 4-13. EXAMPLE OF SPREAD OF TEST DATA OVER TEN TESTS

4.6 PREPARATION OF DATA FOR STATISTICAL ANALYSIS.

The Indenter software program automatically saves all test information in a database. The information in the database can be accessed via a utility included in the program that generates a .cvs file (a comma delimited file that directly imports into Excel) for each test session. A lot of information is included in each file that was not used directly in the data processing. The data fields that were used consisted of test session date, test session time, the modulus values for the ten tests made on the wire, the relaxation values for the ten tests made on the wire, tester name, and test description.

The data obtained during the Indenter tests was transferred from the Indenter software to a spreadsheet. Each row in the spreadsheet corresponds to one Indenter test. All of the tests in the test session have the same date and time stamp that corresponds to the time at which the test session was saved. No distinction is made between test sessions; that is, all of the data points with aging level 0 are considered as independent points.

4.7 AUDITING OF DATA USED FOR STATISTICAL ANALYSIS.

Even though the modulus and relaxation values were obtained directly from the .cvs file without having to be copied by hand, some information still needed to be manually entered into the spreadsheet and some cutting and pasting of data that was needed. Thus, it was important to have independent verification that these steps were done properly.

5. INDENTER TESTING RESULTS AND DISCUSSIONS.

A statistical analysis of all Indenter modulus data was performed by Oberjohn Associates. Since there were five wire samples for each aging level and ten Indenter tests were made by each tester on each sample, the analysis presented the combined information from 150 data points per aging level for each wire type. A variety of plotting techniques was investigated to select one that presented the data in the most meaningful format to help answer the following three questions:

1. Is there a correlation between aging and modulus readings?
2. Does the relaxation value provide useful information?
3. How does test data from different testers compare?

For each wire type, four plots were constructed:

1. Average modulus values and 0.95 confidence level data for each individual tester

2. Combined average modulus data of three testers with a curve fit of the data and 0.95 confidence levels shown

3. Same plot as 1. except for relaxation data instead of modulus

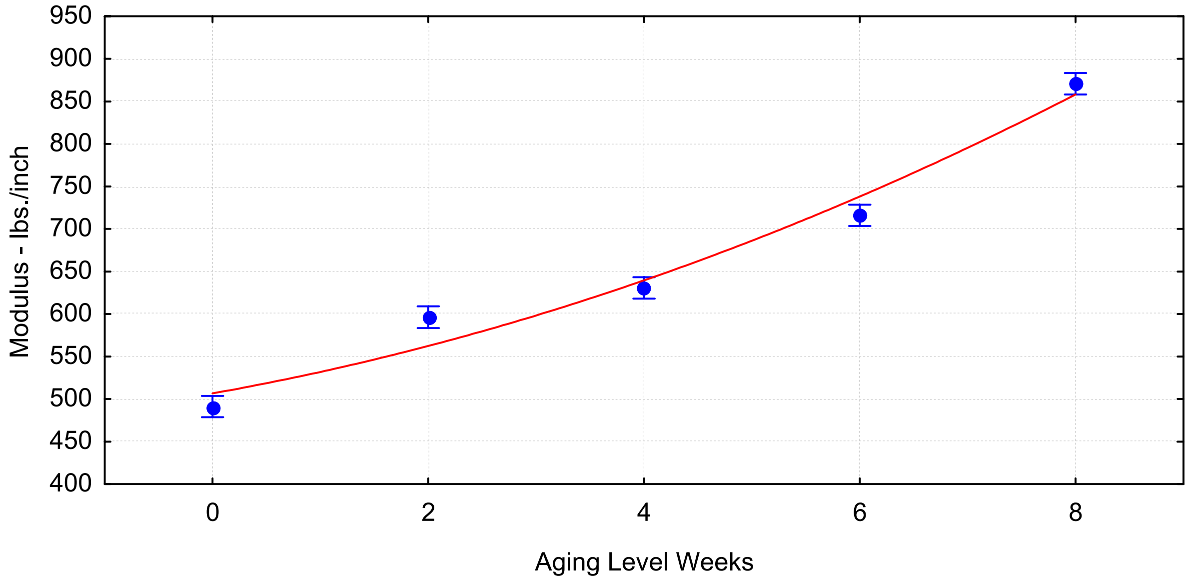
4. Same plot as 2. except for relaxation data instead of modulus

5.1 PVC DATA.

This material was included as the reference wire type because it is a material on which a body of test data already exists from testing in the nuclear industry, and it has a simple construction, representing a single insulation layer. By including PVC, it will demonstrate if Indenter testing of this material on small wire diameters shows the same type of correlation as shown on the larger wire diameters for which data exists.

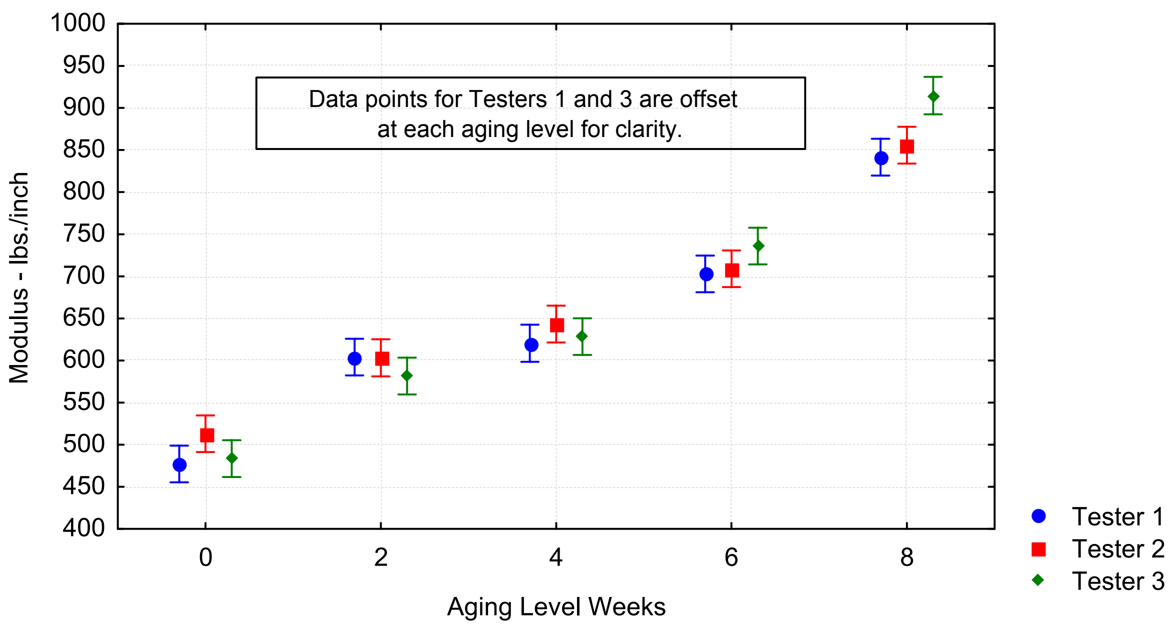
Figures 5-1 through 5-4 show the results for PVC. Figures 5-1 and 5-2 show the Indenter modulus values changed significantly as the material aged. Eight weeks of aging produced an increase of about 78% in the Modulus value, and there was good correlation between levels of aging and increase in modulus. Figures 5-3 and 5-4 show a 33% variation in relaxation values as the material ages. The general shape (convex/concave) of the relaxation curve is the same as the modulus curve; the significance of the shape is not known.

The shape of figure 5-1 (PVC modulus) is similar to PVC plots obtained in other aging or Indenter tests. They exhibit the same characteristic concave-up shape, and the modulus values increase in a well-behaved pattern as the amount of aging time increases. A listing of other reports related to the Indenter and Indenter research is presented in appendix G.



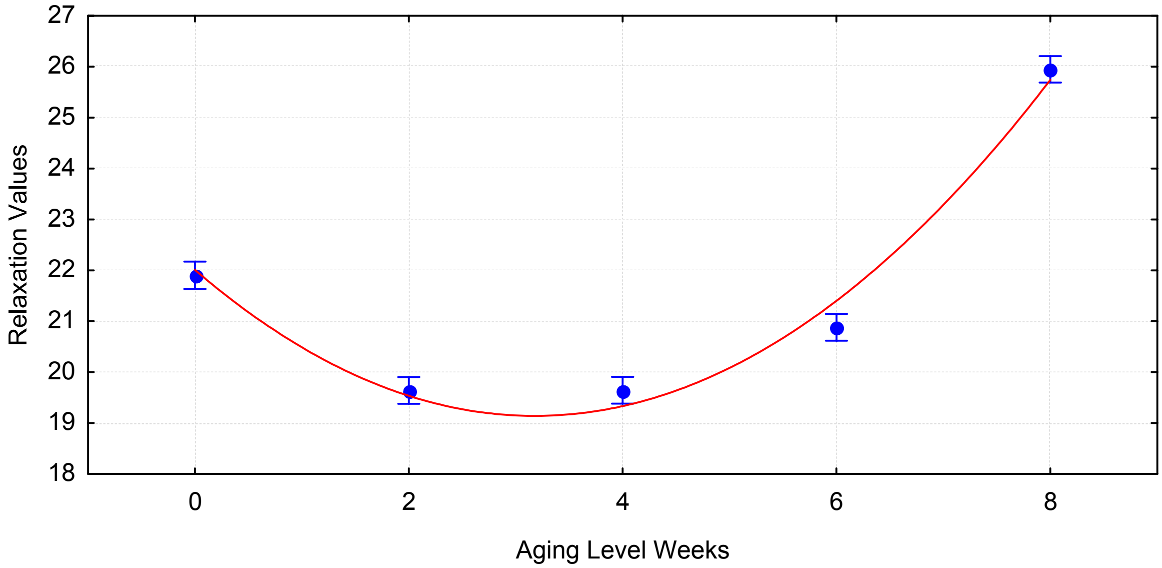
Combined data from three individual testers
Quadratic curve fit of data—solid line
Vertical bars denote 0.95 confidence intervals

FIGURE 5-1. PVC MODULUS AVERAGES



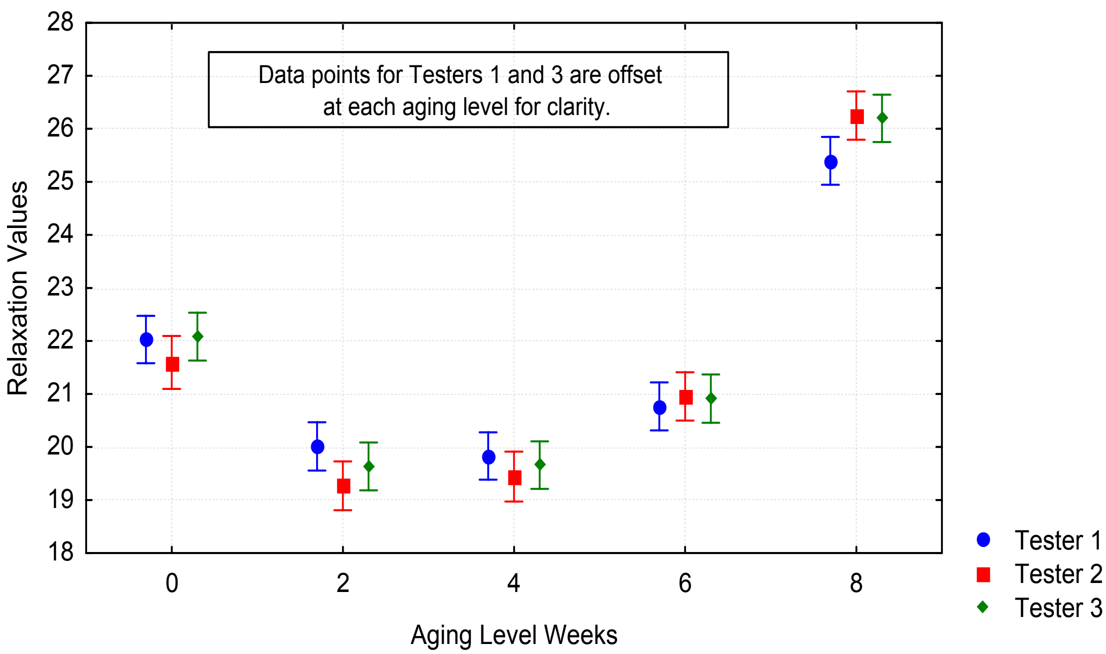
Separate plot for each of three testers
Vertical bars denote 0.95 confidence intervals

FIGURE 5-2. PVC MODULUS INDIVIDUAL TESTERS



Combined data from three individual testers
Quadratic curve fit of data—solid line
Vertical bars denote 0.95 confidence intervals

FIGURE 5-3. PVC RELAXATION AVERAGES

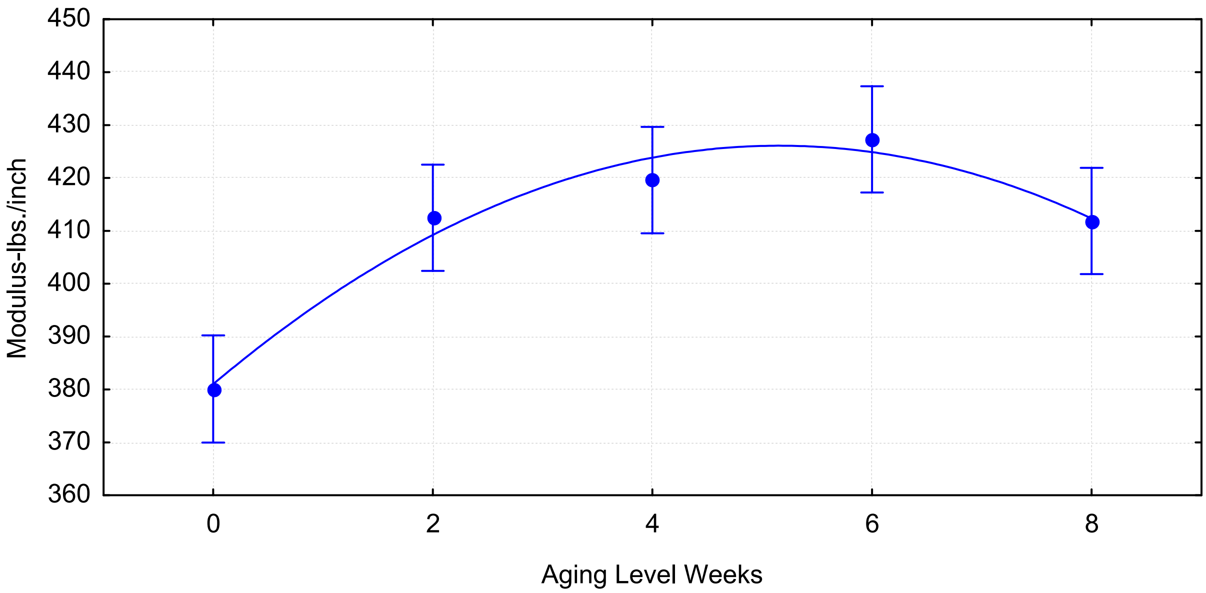


Separate plot for each of three testers
Vertical bars denote 0.95 confidence intervals

FIGURE 5-4. PVC RELAXATION INDIVIDUAL TESTERS

5.2 PVC G-N DATA.

The PVC G-N insulation system consists of a clear nylon outer insulation covering a fiberglass weave that is in turn covering a PVC coating on the conductor. Figures 5-5 through 5-8 show the results for PVC G-N. Figures 5-5 and 5-6 show the modulus values changed moderately as the material aged. Eight weeks of aging produced a change of approximately 13% in the modulus value, and there was a moderate correlation between levels of aging and increase in modulus. There was a small increase in modulus up to the 6-week aging level, but after that the modulus decreases slightly, which was not expected. Figures 5-7 and 5-8 show a 4% variation in relaxation values as the material ages. The general shape (convex/concave) of the relaxation curve is opposite to that of the modulus curve, and this material is the only one of the six tested whose curve shapes were different from each other. The significance of the shape is not known. Since neither the modulus nor relaxation data changed significantly during the 8-week aging period, no conclusion was reached as to whether or not this behavior reflected the actual condition of the wire or just difficulty in obtaining meaningful data for this insulation system.



Combined data from three individual testers
Quadratic curve fit of data—solid line
Vertical bars denote 0.95 confidence intervals

FIGURE 5-5. PVC G-N MODULUS AVERAGES

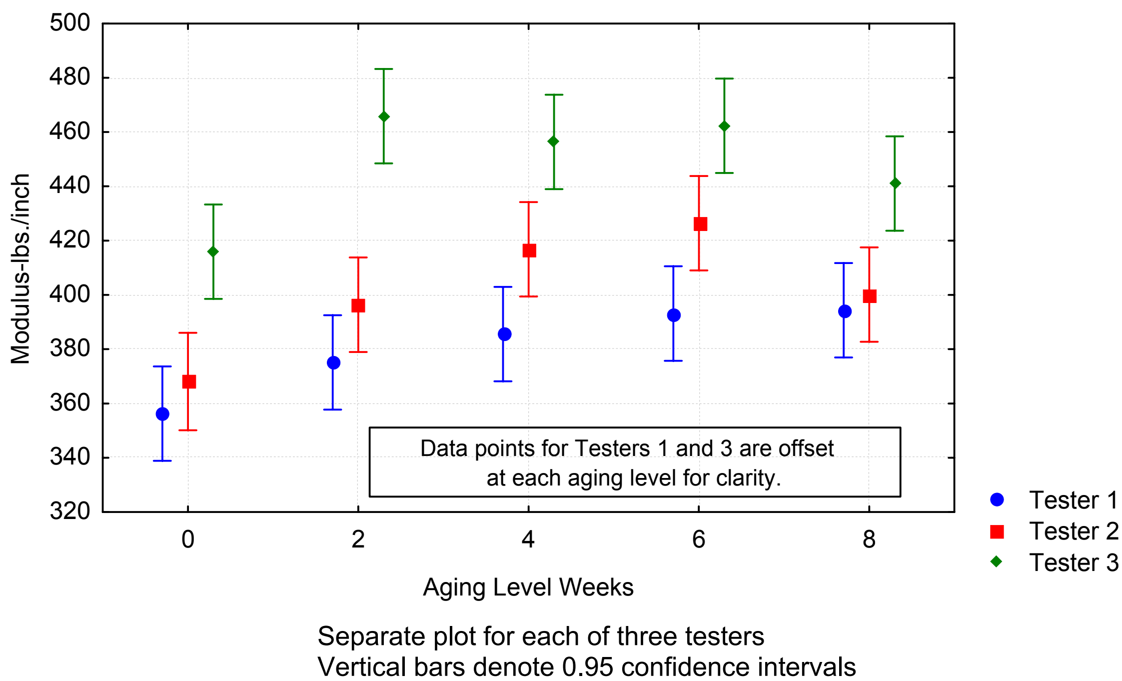


FIGURE 5-6. PVC G-N MODULUS INDIVIDUAL TESTERS

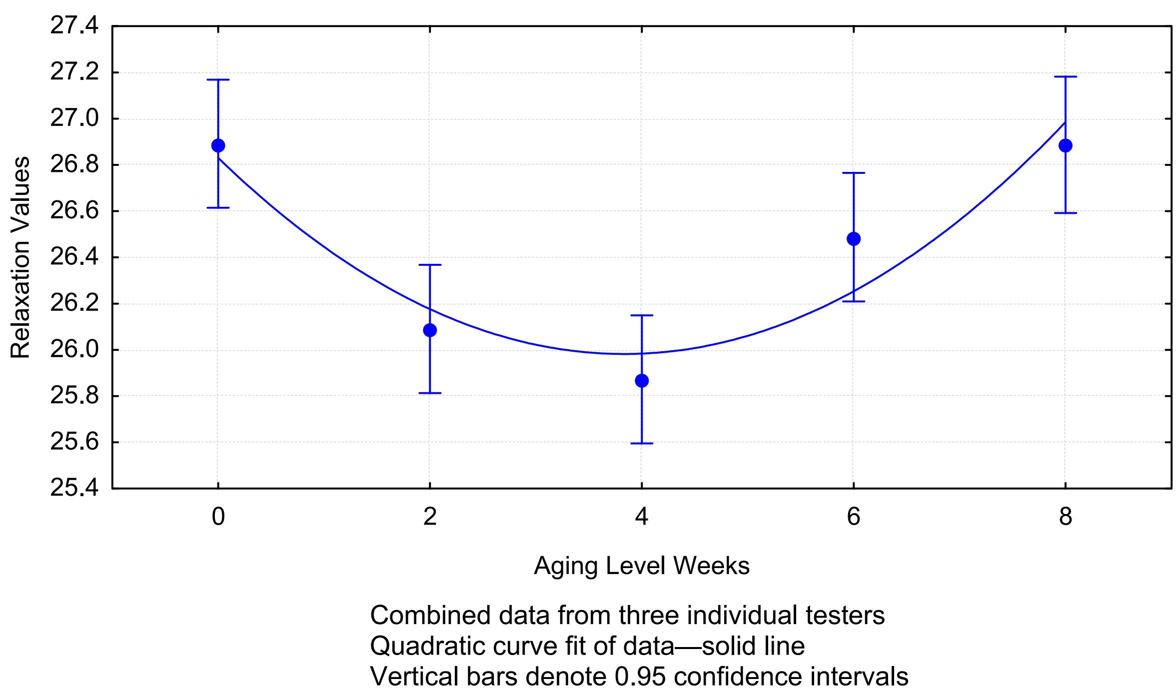


FIGURE 5-7. PVC G-N RELAXATION AVERAGES

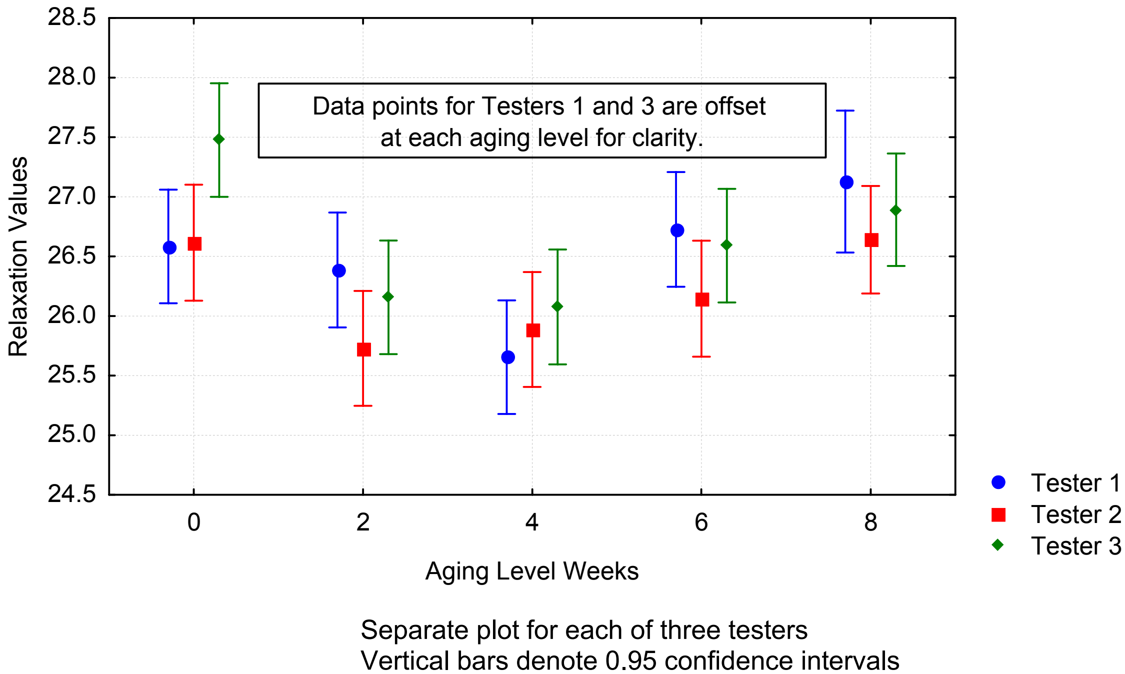
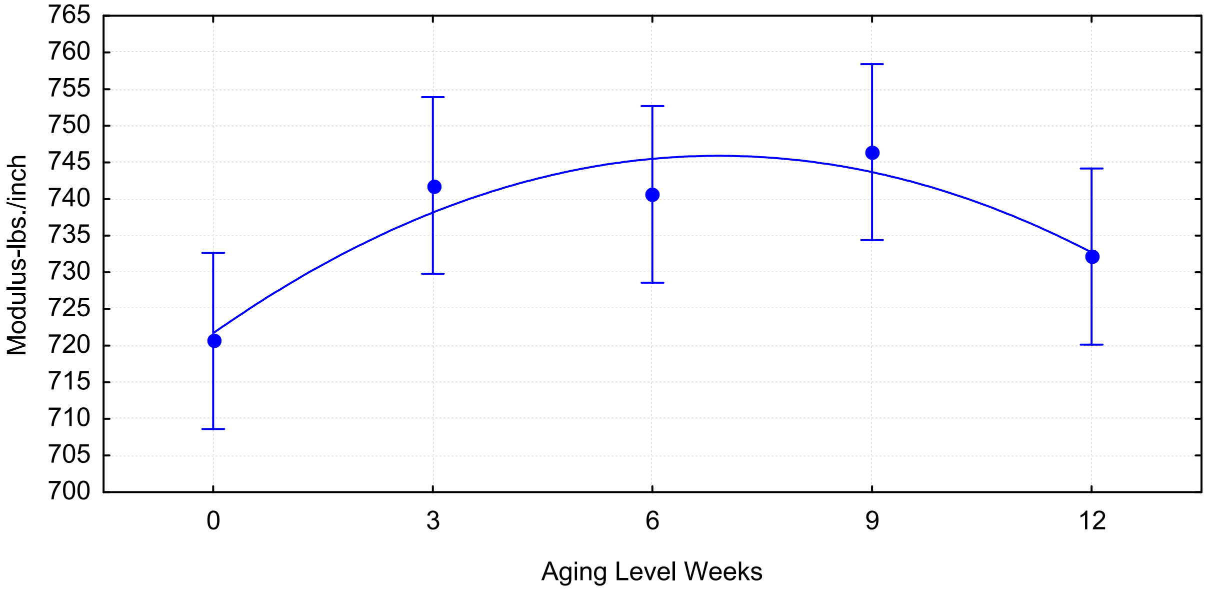


FIGURE 5-8. PVC G-N RELAXATION INDIVIDUAL TESTERS

5.3 XL-ETFE DATA.

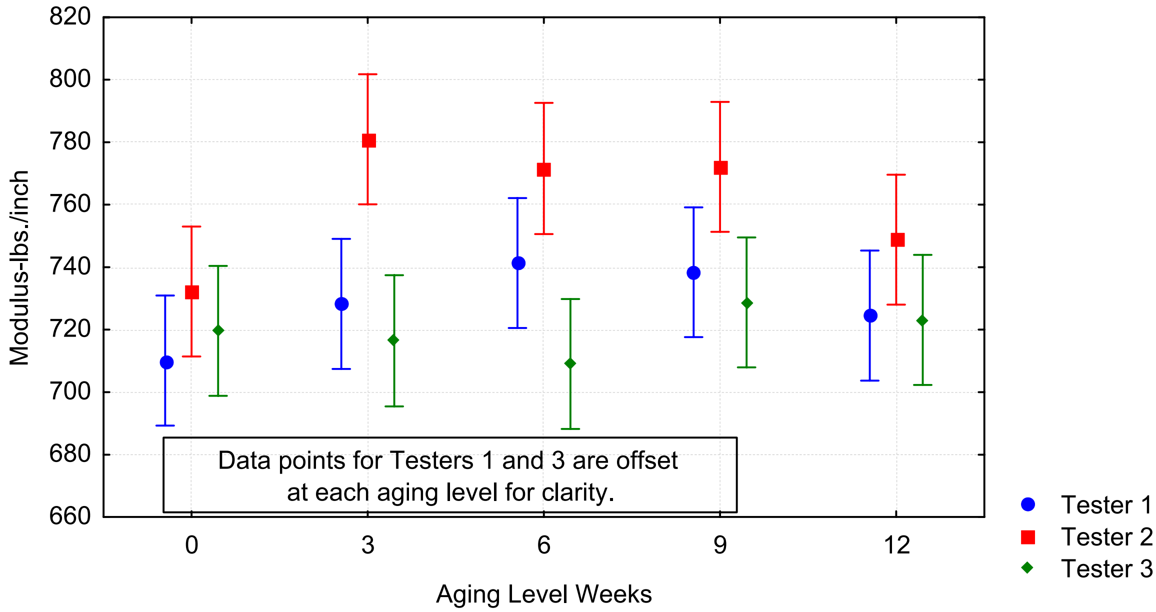
The XL-ETFE insulation system consists of an outer FP wrap over a FP/Polyimide/FP wrap over the conductor. Figures 5-9 through 5-12 show the results for XL-ETFE. Figures 5-9 and 5-10 show the modulus values changed only slightly as the material aged. Twelve weeks of aging produced a change of approximately 4% in the modulus value, and there was essentially no correlation between levels of aging and increase in modulus. The 4% change is less than the assumed accuracy of the Indenter.* Figures 5-11 and 5-12 show an 18% variation in relaxation values as the material ages, but essentially all the change occurred within the first 3 weeks of aging. The general shape (convex/concave) of the relaxation curve is the same as the modulus curve, but the significance of the shape is not known. Since the percentage changes in the modulus and relaxation data were small and there were no identifiable trends in the curves, no meaningful conclusion was reached concerning this insulation system.

* The assumed accuracy of the Indenter is ±10% of the reading obtained for either modulus or relaxation. Experience indicates that this value is very conservative; however, a detailed study has not been performed to determine an actual value.



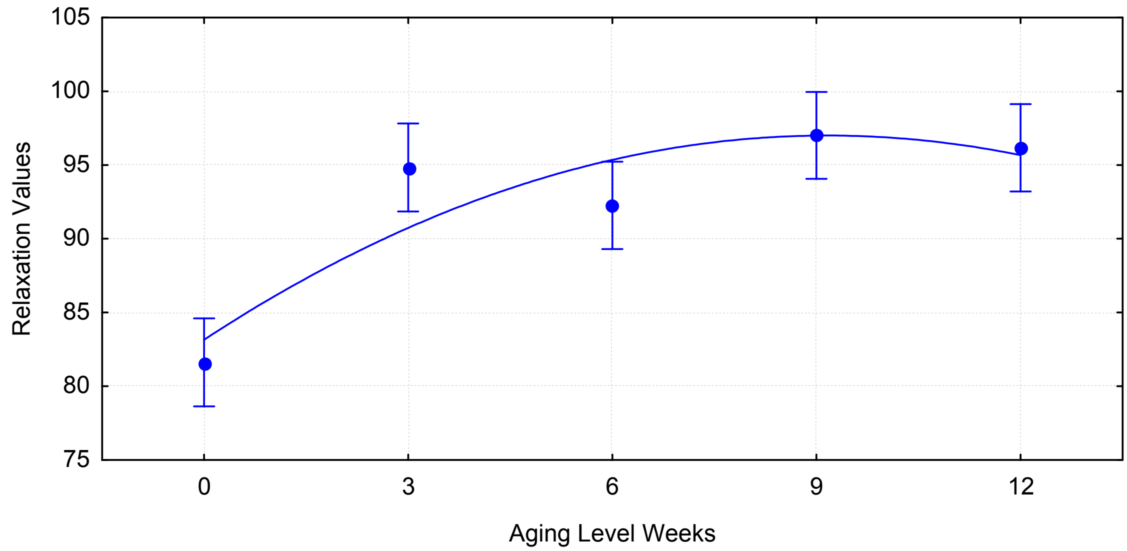
Combined data from three individual testers
Quadratic curve fit of data—solid line
Vertical bars denote 0.95 confidence intervals

FIGURE 5-9. XL-ETFE MODULUS AVERAGES



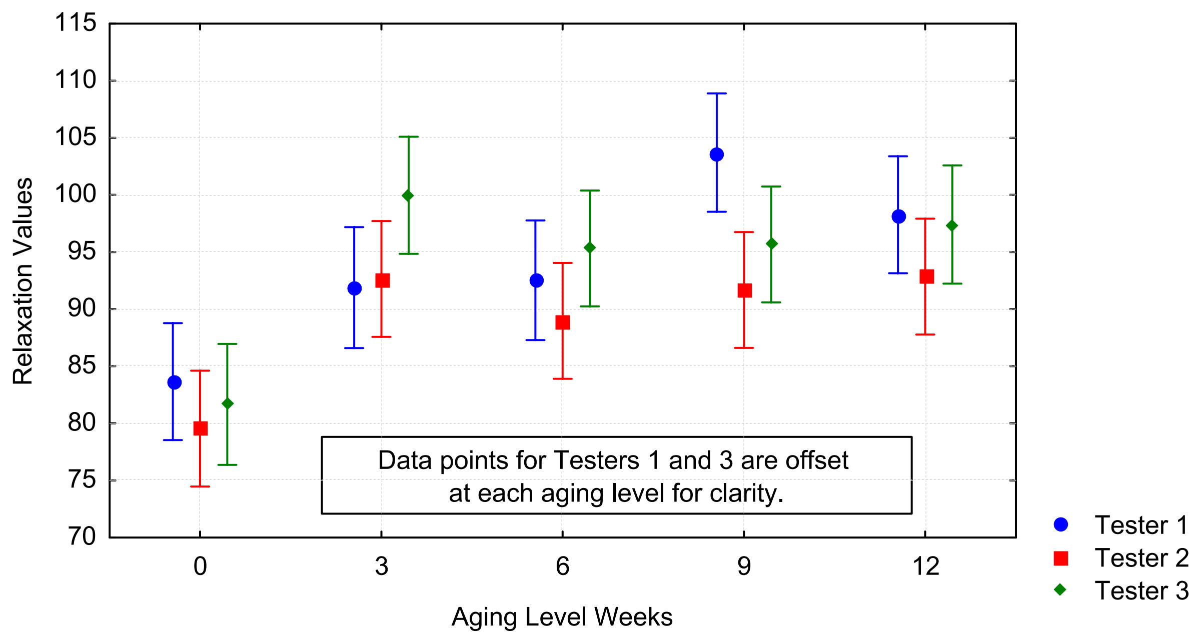
Separate plot for each of three testers
Vertical bars denote 0.95 confidence intervals

FIGURE 5-10. XL-ETFE MODULUS INDIVIDUAL TESTERS



Combined data from three individual testers
Quadratic curve fit of data—solid line
Vertical bars denote 0.95 confidence intervals

FIGURE 5-11. XL-ETFE RELAXATION AVERAGES



Separate plot for each of three testers
Vertical bars denote 0.95 confidence intervals

FIGURE 5-12. XL-ETFE RELAXATION INDIVIDUAL TESTERS

5.4 COMPOSITE TKT DATA.

The Composite TKT insulation system consists of three layers over the conductor: Teflon®/Kapton®/Teflon®. Figures 5-13 through 5-16 show the results for Composite TKT. Figures 5-13 and 5-14 show the modulus values changed slightly as the material aged. Twelve weeks of aging produced a change of approximately 7% in the modulus value, and there was essentially no correlation between levels of aging and increase in modulus. The 7% change is approximately the same as the assumed accuracy of the Indenter. Figures 5-15 and 5-16 show a 5% variation in relaxation values as the material ages, but essentially all the change occurred after 9 weeks of aging. The general shape (convex/concave) of the relaxation curve is the same as the modulus curve, but the significance of the shape is not known. Since the percentage changes in the modulus and relaxation data were both small and there were no identifiable trends in the curves, no meaningful conclusion was reached concerning this insulation system.

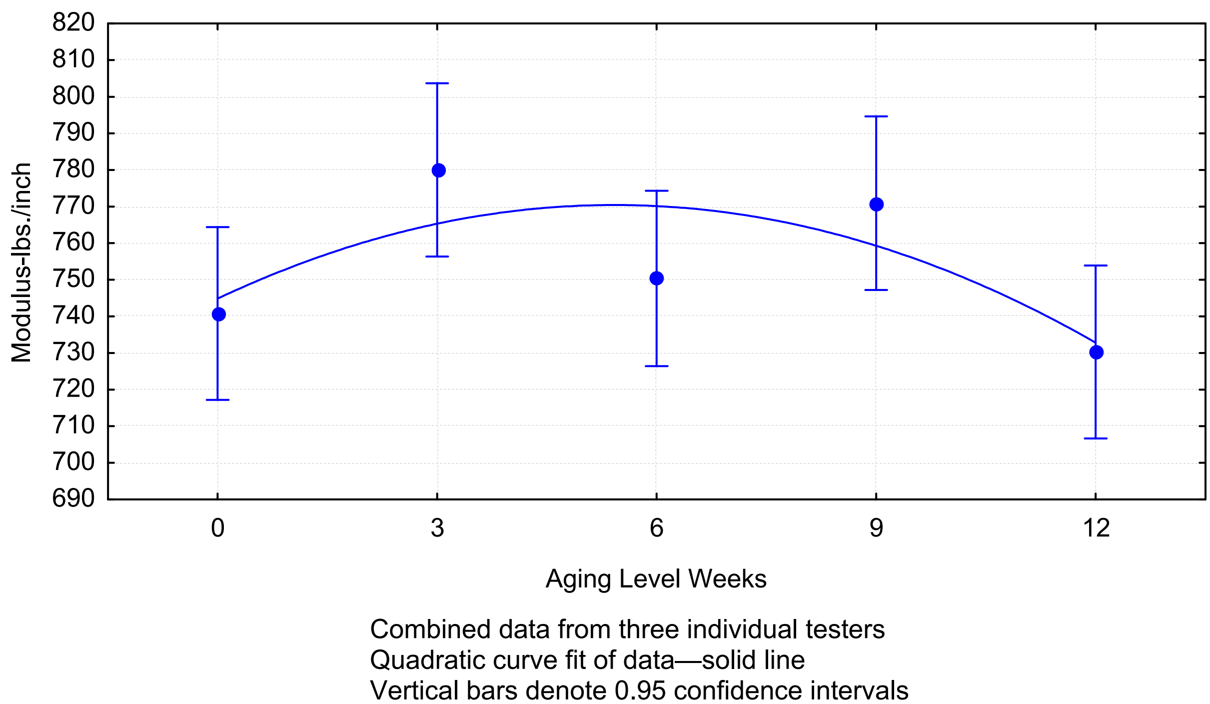
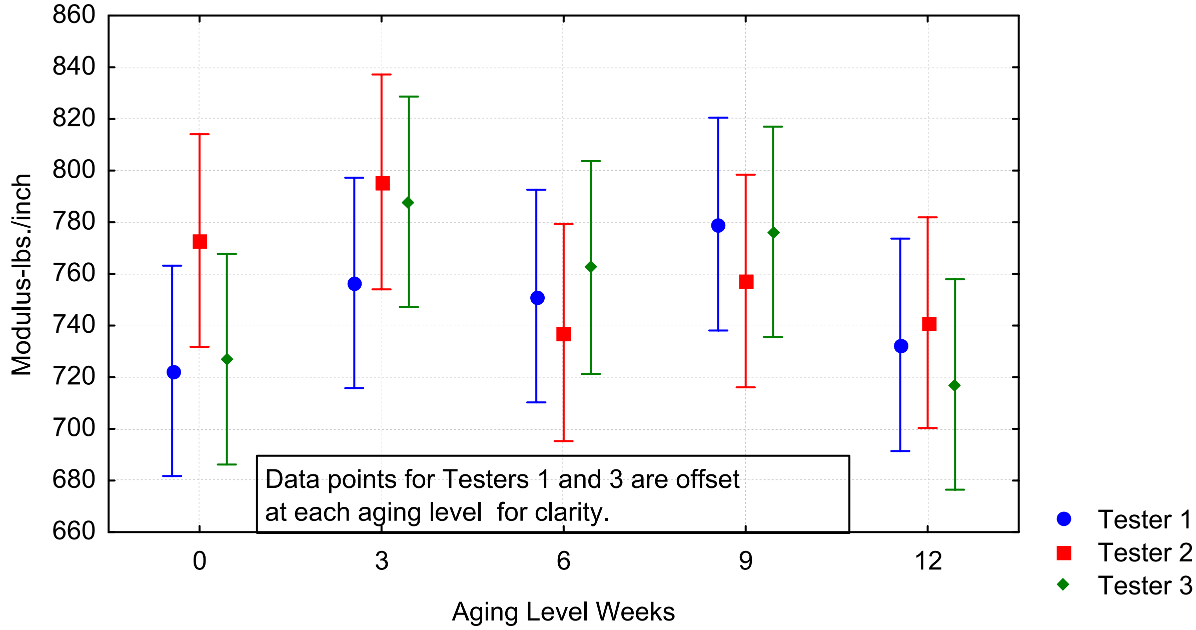
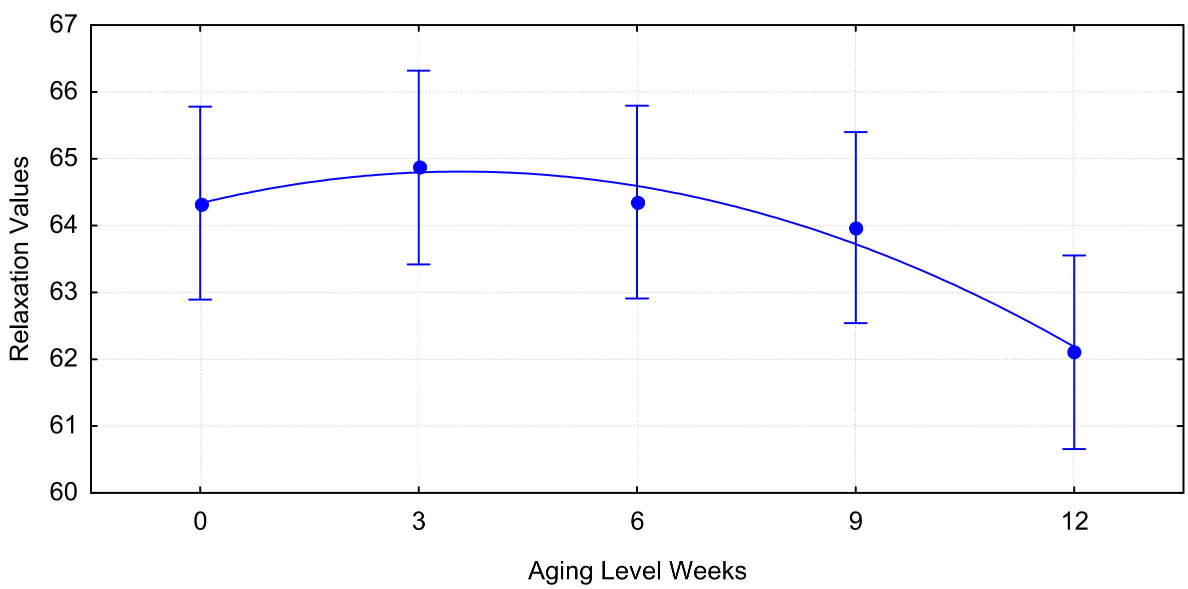


FIGURE 5-13. COMPOSITE TKT MODULUS AVERAGES



Separate plot for each of three testers
Vertical bars denote 0.95 confidence intervals

FIGURE 5-14. COMPOSITE TKT MODULUS INDIVIDUAL TESTERS



Combined data from three individual testers
Quadratic curve fit of data—solid line
Vertical bars denote 0.95 confidence intervals

FIGURE 5-15. COMPOSITE TKT RELAXATION AVERAGES

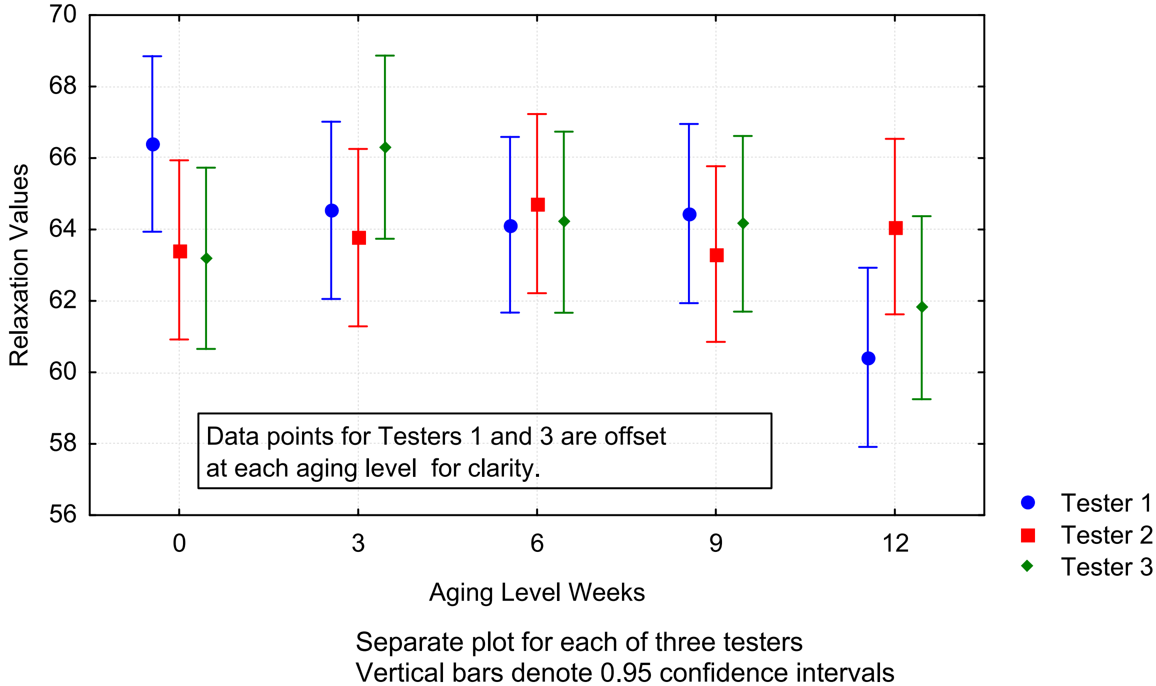
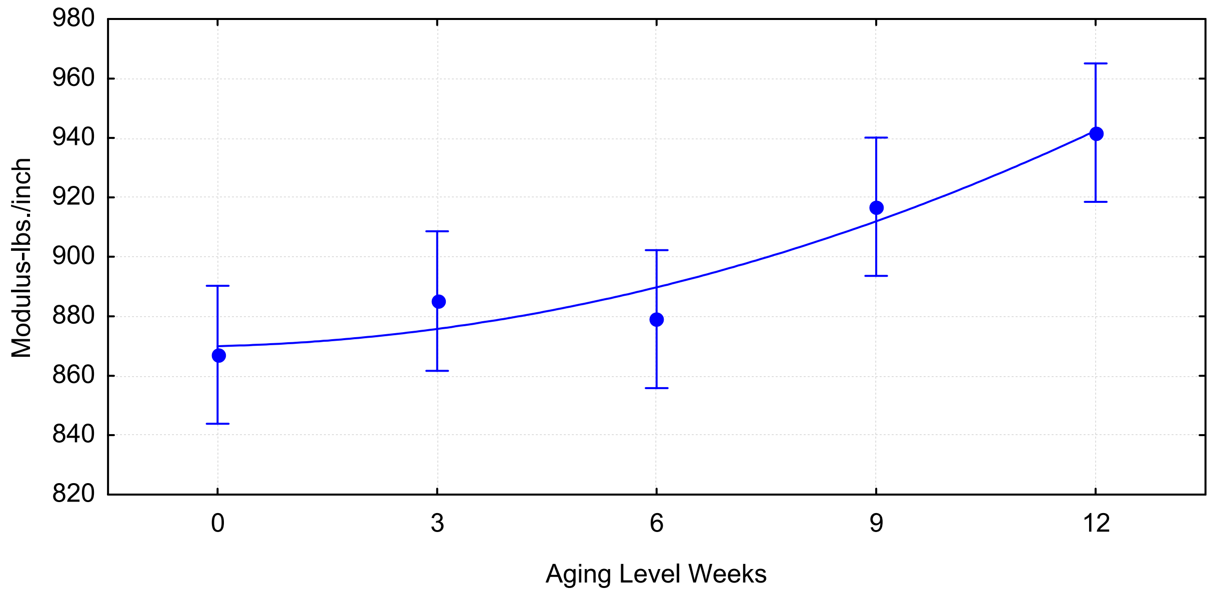


FIGURE 5-16. COMPOSITE TKT RELAXATION INDIVIDUAL TESTERS

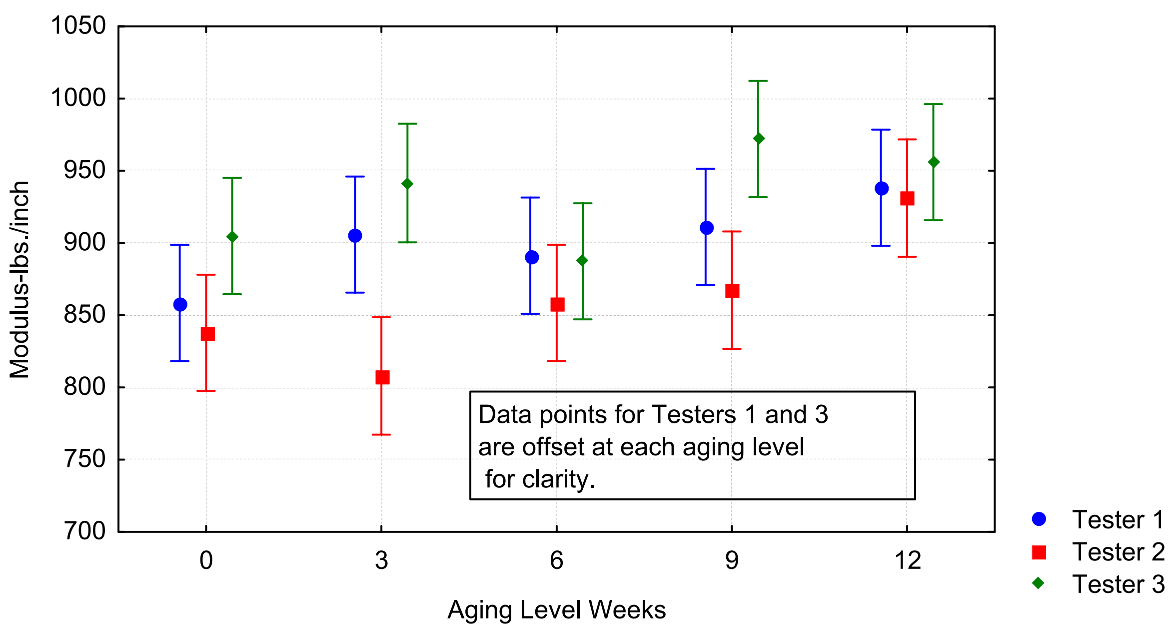
5.5 POLYIMIDE INSULATION DATA.

This polyimide insulation system consists solely of aromatic polyimide. Figures 5-17 through 5-20 show the results for Polyimide INST. Figures 5-17 and 5-18 show that the modulus values changed slightly as the material aged. Twelve weeks of aging produced a change of approximately 8% in the modulus value, and there appears to be good correlation between levels of aging and increase in modulus. The 8% change is approximately the same as the assumed accuracy of the Indenter. Figures 5-19 and 5-20 show a 9% variation in relaxation values as the material ages, and there appears to be a reasonable correlation between levels of aging and increase in relaxation. The general shape (convex/concave) of the relaxation curve is the same as the modulus curve, but the significance of the shape is not known. Although the percentage changes in the modulus and relaxation data were both small, there were identifiable trends in the curves for both values. Thus, it appears that the Indenter can monitor aging in this insulation system.



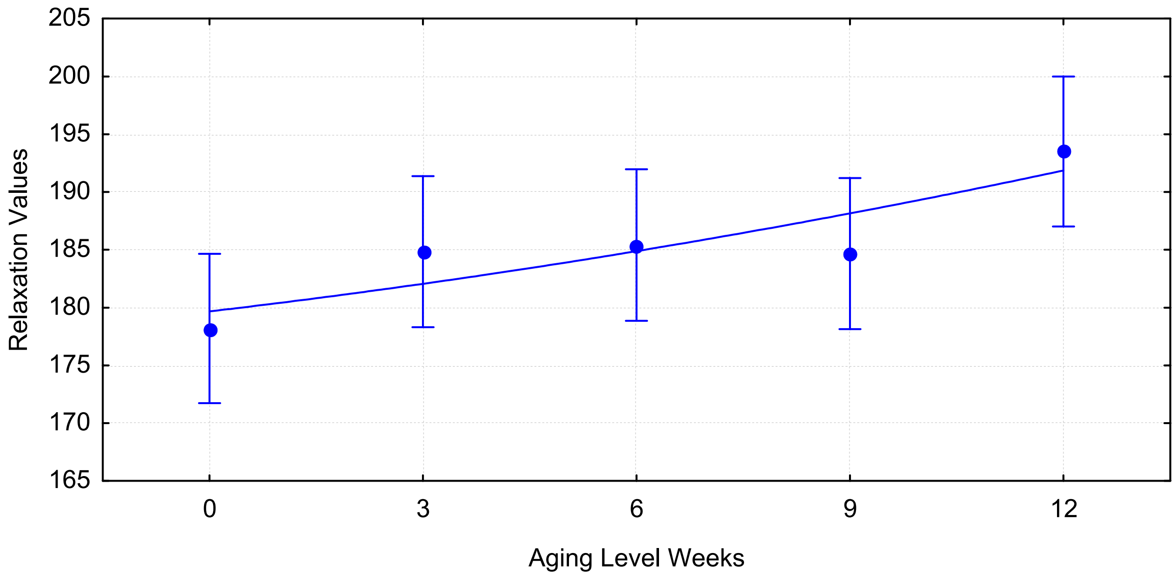
Combined data from three individual testers
Quadratic curve fit of data—solid line
Vertical bars denote 0.95 confidence intervals

FIGURE 5-17. POLYIMIDE INST MODULUS AVERAGES



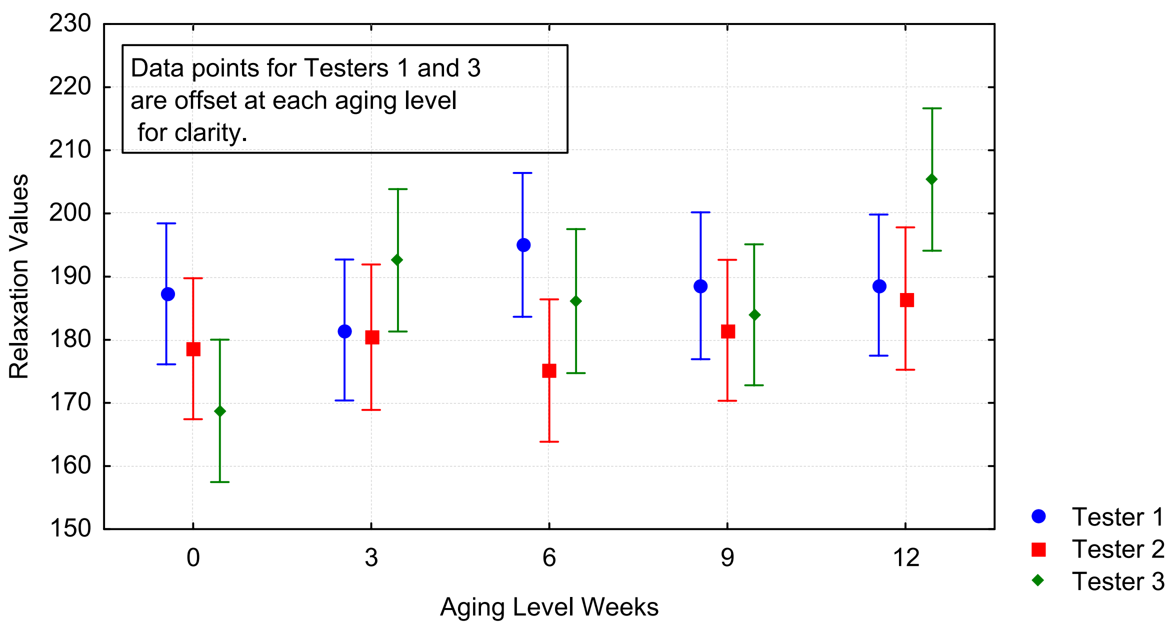
Separate plot for each of three testers
Vertical bars denote 0.95 confidence intervals

FIGURE 5-18. POLYIMIDE INST MODULUS INDIVIDUAL TESTERS



Combined data from three individual testers
Quadratic curve fit of data—solid line
Vertical bars denote 0.95 confidence intervals

FIGURE 5-19. POLYIMIDE INST RELAXATION AVERAGES

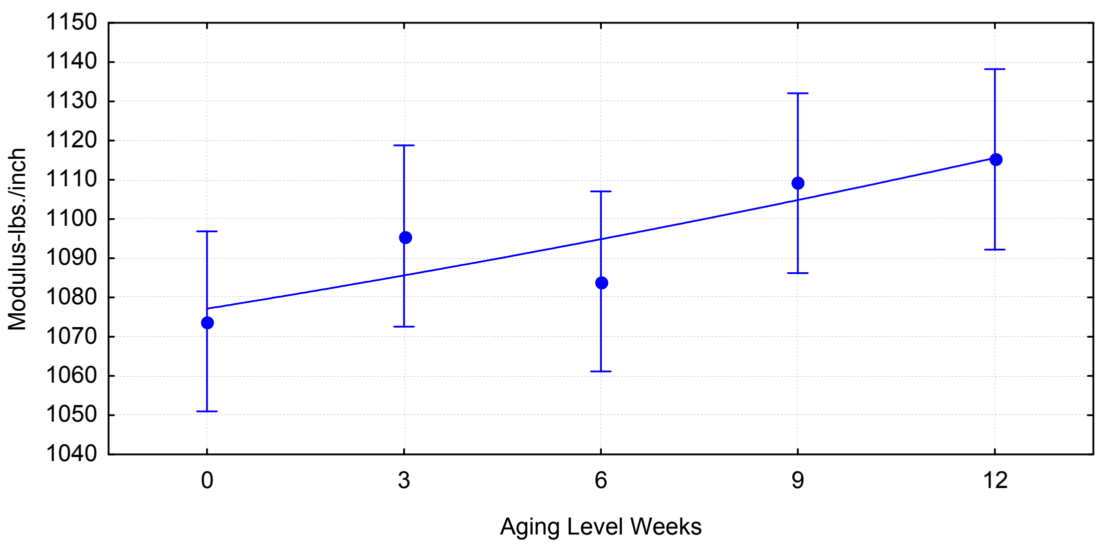


Separate plot for each of three testers
Vertical bars denote 0.95 confidence intervals

FIGURE 5-20. POLYIMIDE INST RELAXATION INDIVIDUAL TESTERS

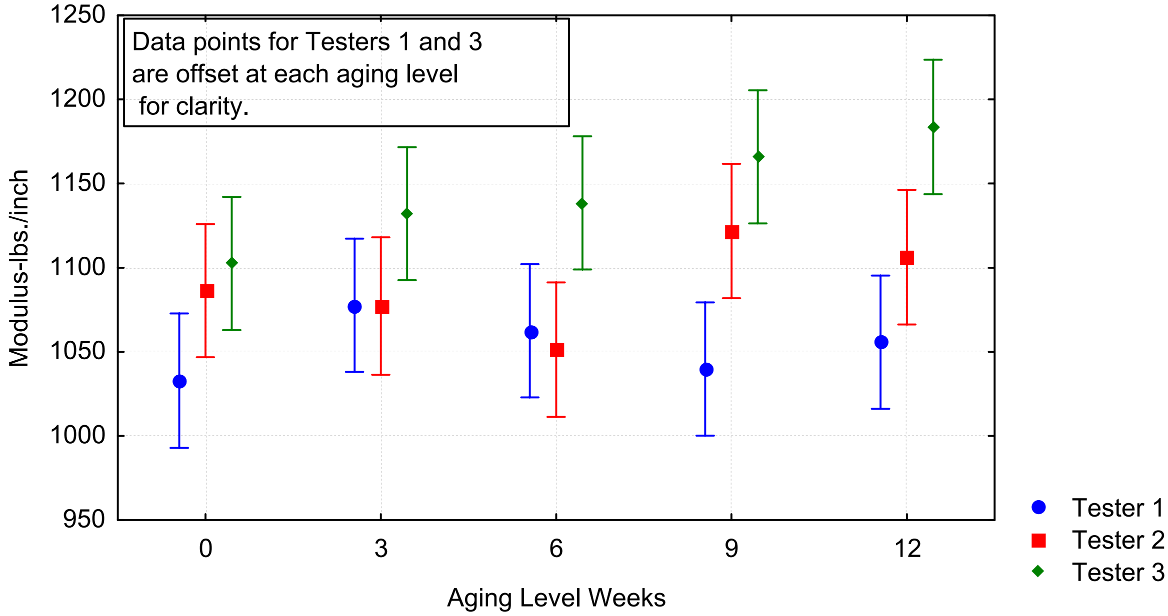
5.6 POLYIMIDE POWER DATA.

This polyimide insulation system (MIL-DTL-22759/86A) is a composite construction of PTFE followed by aromatic polyimide, followed by another layer of PTFE. Figures 5-21 through 5-24 show the results for Polyimide Power. Figures 5-21 and 5-22 show the modulus values changed very slightly as the material aged. Twelve weeks of aging produced a change of approximately 4% in the modulus value, and there was only a slight correlation between levels of aging and increase in modulus. The 4% change is less than the assumed accuracy of the Indenter. Figures 5-23 and 5-24 show a 2% variation in relaxation values as the material aged. The general shape (convex/concave) of the relaxation curve is the same as the modulus curve, but the significance of the shape is not known. Since the percentage changes in the modulus and relaxation data were both very small and there were no identifiable trends in the curves, no meaningful conclusion was reached concerning this insulation system. Although the name given to this insulation system for this research indicates that it is similar to Polyimide INST, the construction is actually what is used in the Composite TKT, and the general Indenter results were like those obtained for Composite TKT.



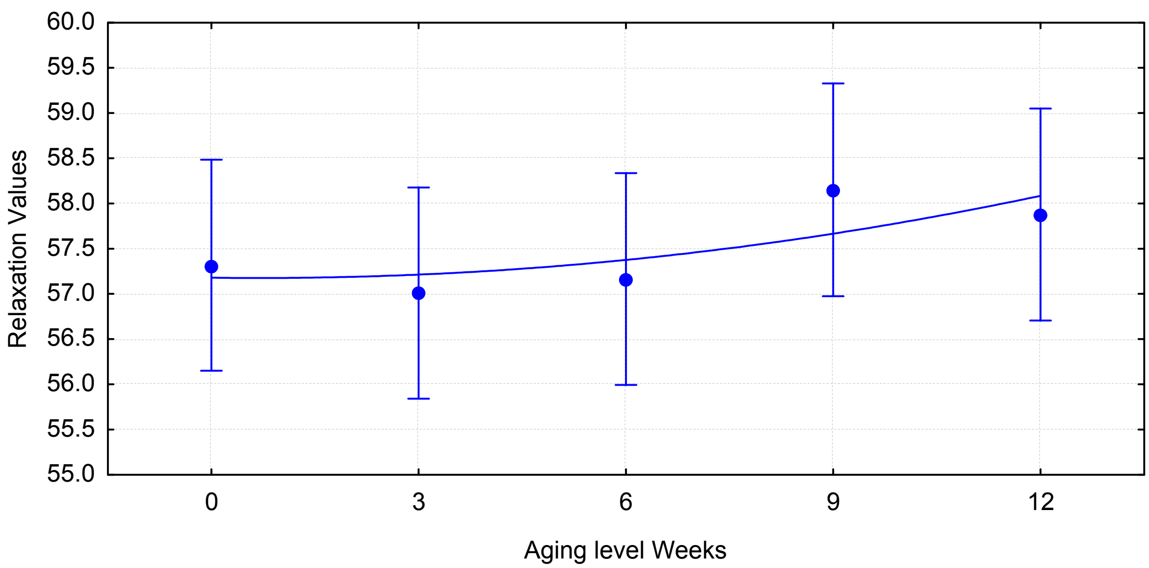
Combined data from three individual testers
Quadratic curve fit of data—solid line
Vertical bars denote 0.95 confidence intervals

FIGURE 5-21. POLYIMIDE POWER MODULUS AVERAGES



Separate plot for each of three testers
Vertical bars denote 0.95 confidence intervals

FIGURE 5-22. POLYIMIDE POWER MODULUS INDIVIDUAL TESTERS



Combined data from three individual testers
Quadratic curve fit of data—solid line
Vertical bars denote 0.95 confidence intervals

FIGURE 5-23. POLYIMIDE POWER RELAXATION AVERAGES

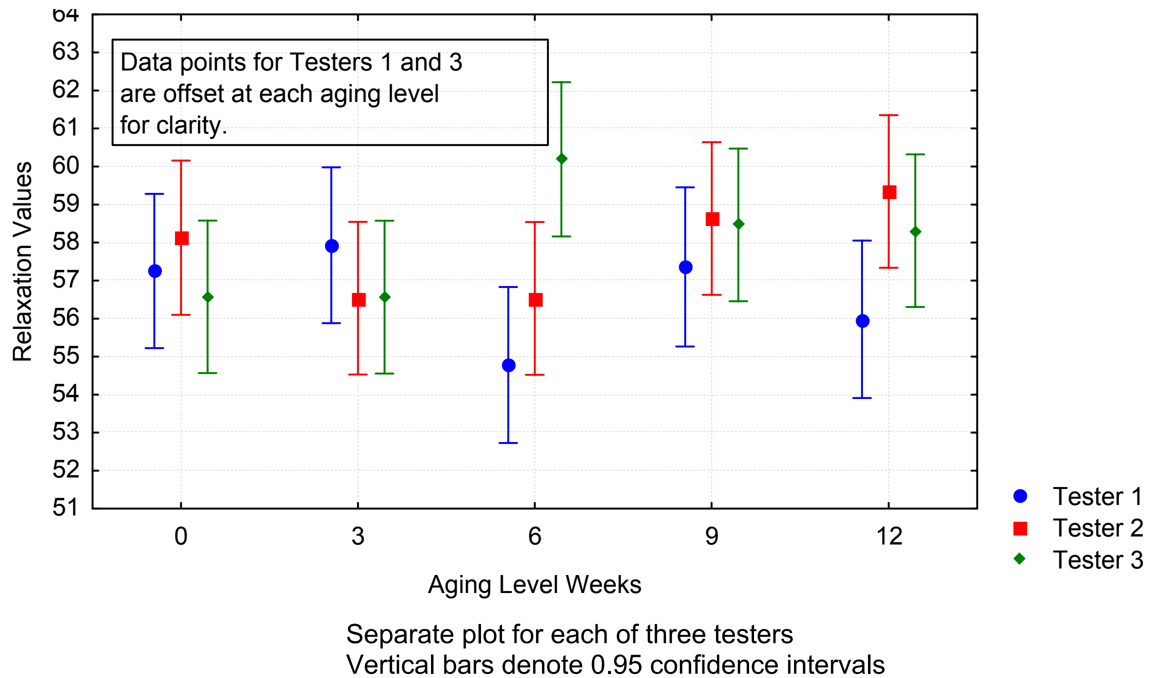


FIGURE 5-24. POLYIMIDE POWER RELAXATION INDIVIDUAL TESTERS

5.7 VARIATION IN DATA AMONG TESTERS.

Table 5-1 shows the percent variation in modulus and relaxation values that the 0.95 confidence level represents. The small range of values from 1 to 7 indicates that the experience of the user is not a factor in obtaining data.

TABLE 5-1. PERCENT VARIATION FROM AVERAGE AFTER 8 WEEKS OF AGING (For 0.95 Confidence Interval)

Wire Type	Modulus				Relaxation			
	Avg	Max	Min	±%	Avg	Max	Min	±%
PVC	870	885	855	1.7	25.9	26.1	25.8	0.6
PVC G-N	411	421	402	2.3	26.9	27.2	26.6	1.1
XL-ETFE	733	745	720	1.7	96	99	93	3.1
Composite TKT	730	753	708	3.1	62.1	63.5	60.7	2.3
Polyimide INST	942	964	920	2.3	194	200	187	3.4
Polyimide Power	1115	1139	1091	2.2	57.9	59.0	56.7	2.0

Example: For PVC, the longest aging level was 8 weeks. The longest aging level was used since it would typically show the greatest variation. The average modulus reading for each of the three testers was 870. The 0.95 confidence interval for that aging level showed a maximum modulus reading of 885 and a minimum of 855 for a difference of 30. Dividing this difference by the average number (870) gives a total percent variation from the maximum to minimum of 3.4 % or a ± difference from the average of 1.7%.

5.8 CHANGE IN MODULUS AND RELAXATION VALUES.

Tables 5-2 and 5-3 show the change in the modulus and relaxation values caused by the accelerated thermal aging exposures from the six wire types. High and low values are not necessarily the values associated with the highest and lowest aging levels because some values decreased at the higher aging levels.

TABLE 5-2. CHANGE OF MODULUS VALUES OVER FIVE AGING LEVELS

Wire Type	Modulus Values			
	High	Low	Diff	% Change
PVC	870	490	380	77
PVC G-N	428	380	48	13
XL-ETFE	746	720	26	4
Composite TKT	780	730	50	7
Polyimide INST	940	870	70	8
Polyimide Power	1115	1072	43	4

TABLE 5-3. CHANGE OF RELAXATION VALUES OVER FIVE AGING LEVELS

Wire Type	Relaxation Values			
	High	Low	Diff	% Change
PVC	26.0	19.5	6.5	33
PVC G-N	26.9	25.9	1.0	4
XL-ETFE	97	82	15	18
Composite TKT	65	62	3	5
Polyimide INST	194	178	16	9
Polyimide Power	58.1	57.0	1.1	2

6. WIRE INSULATION DETERIORATION ANALYSIS SYSTEM TESTING.

The original test plan anticipated using EAB testing to measure the effects of accelerated thermal aging, but it was determined that the wrapped nature of polyimide insulation precludes obtaining meaningful data from EAB testing. Therefore, the test plan was modified to incorporate WIDAS testing on Polyimide INST and Polyimide Power wires to examine how the results of this method correlated to Indenter data. The WIDAS process is a sampling test that determines the amount of deterioration that has occurred in wire insulation (see appendix F for more details). Wire insulation was defined as failed when cracks developed to the point that significant electrical leakage current occurred.

6.1 WIRE INSULATION DETERIORATION ANALYSIS SYSTEM TEST PROCEDURE.

The hydrolysis test measured the life of the insulation under predetermined strain when in contact with water at an elevated temperature. Each of the ten specimens from the five different thermal aging levels were wrapped around a mandrel whose diameter is eight to ten times the wire diameter, the length of wire wrap being 1 foot. The specimens were then submerged in distilled water and the temperature was raised to 95°C. Electrical proof tests to check the insulation integrity were conducted at 2500 Vac root mean square (rms) applied for 10 seconds. A specimen was considered to have failed when the leakage current from the proof tests exceeded 2 mA. The proof tests were conducted at a time of 0, 5, 17.5, 30 hours and followed by a test every 12 hours. The specimens were not energized during the aging, except during the proof tests, thus creating no aging by voltage stress.

6.2 WIRE INSULATION DETERIORATION ANALYSIS SYSTEM TEST RESULTS.

Table 6-1 is a comparative summary of the duration of thermal-aging exposures and average time to failure during the WIDAS tests.

TABLE 6-1. THERMAL-AGING TIME VERSUS WIDAS TIME TO FAILURE

Specimen	Thermal Aging Time	WIDAS Time to Failure (hrs)
Polyimide Inst	0 Weeks	34.70
Polyimide Inst	3 Weeks	31.08
Polyimide Inst	6 Weeks	31.08
Polyimide Inst	9 Weeks	29.85
Polyimide Inst	12 Weeks	26.18
Polyimide Power	0 Weeks	478.67
Polyimide Power	3 Weeks	234.67
Polyimide Power	6 Weeks	280.00
Polyimide Power	9 Weeks	212.00
Polyimide Power	12 Weeks	246.67

The WIDAS test data was plotted in the same format as the Indenter test data presented in sections 5.1 through 5.6, including curve fitting and a vertical bar for 0.95 confidence levels. Figures 6-1 and 6-2 compare the thermal aging level to the average number of hours to failure in the WIDAS test for the Polyimide INST and Polyimide Power, respectively.

Figure 6-1 shows a good correlation with aging even though the change in the values for average hour fail time is small. However, the 0.95 confidence level showed the data variation to be quite high.

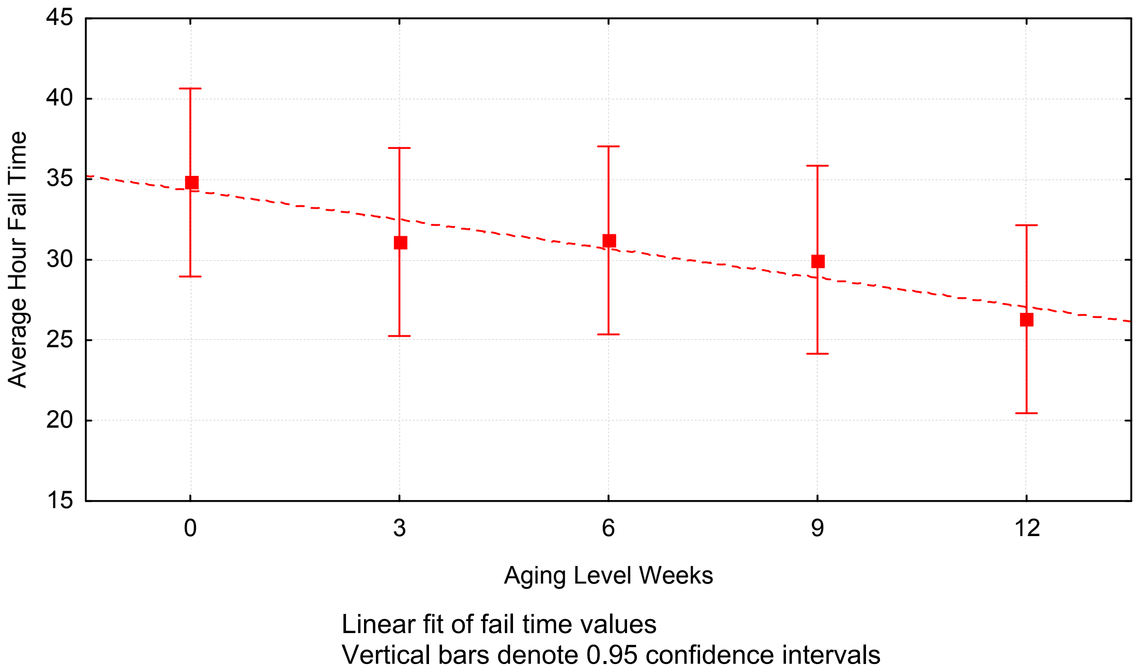
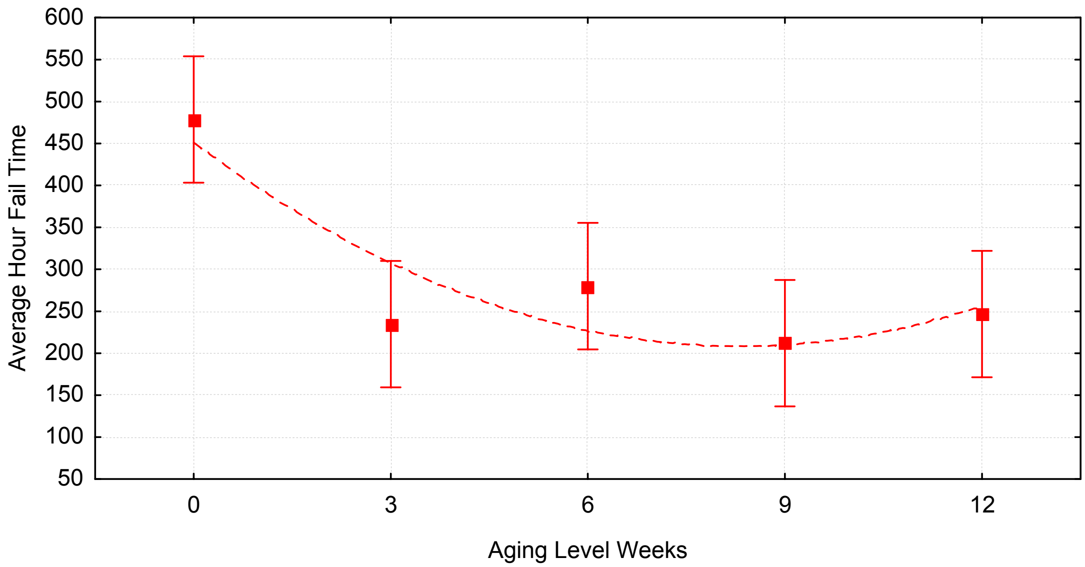


FIGURE 6-1. POLYIMIDE INST—WIDAS LIFE VERSUS AGING LEVELS

Figure 6-2 does not show good correlation with aging, and the future trend of the curve-fitted data exhibits behavior that was not expected to occur; that is, additional thermal aging should have not increase the number of hours to failure in the WIDAS test. The 0.95 confidence level showed data variation to be quite high. Although the generic name for this insulation system is polyimide, its construction is significantly different from that for Polyimide INST. Thus, its WIDAS behavior was not necessarily expected to be similar.



Quadratic curve fit of fail time values
Vertical bars denote 0.95 confidence intervals

FIGURE 6-2. POLYIMIDE POWER—WIDAS LIFE VERSUS AGING LEVELS

The results from the WIDAS test were used to estimate the amount of accelerated thermal aging that would have been necessary to produce an end-of-life condition. The estimate is based on a simple linear regression of the data. The results shown in figures 6-3 and 6-4, project the following aging requirements:

- End-of-life for Polyimide INST is 56 weeks of oven aging
- End-of-life for Polyimide Power is 24 weeks of oven aging

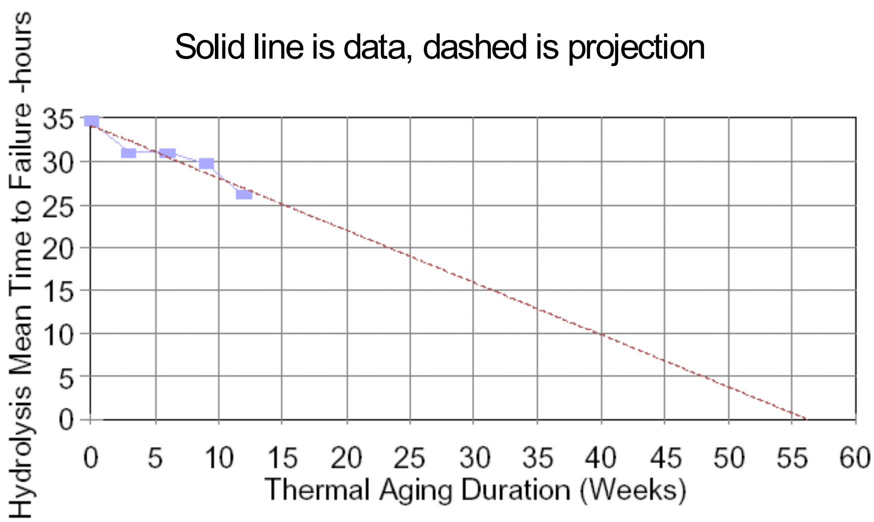


FIGURE 6-3. POLYIMIDE INST—WIDAS PROJECTED LIFE

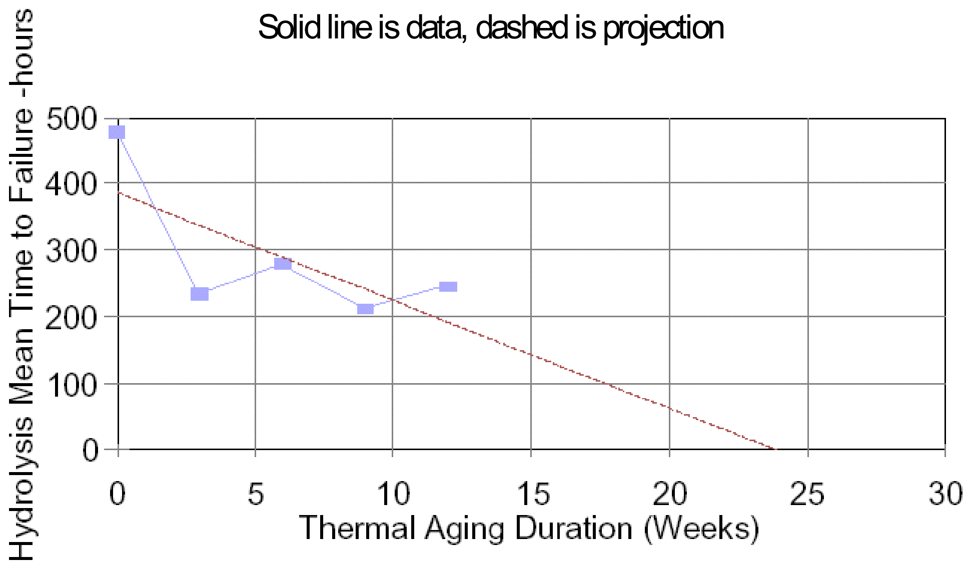


FIGURE 6-4. POLYIMIDE POWER—WIDAS PROJECTED LIFE

The longest aging level done in the accelerated thermal aging exposures was 12 weeks. Based on the theoretical projections to end-of-life, the actual aging performed produced the following conditions:

- The Polyimide INST was aged to 21% [12/56] of its lifetime
- The Polyimide Power was aged to 50% [12/24] of its lifetime

7. COMPARISON OF EAB, INDENTER, AND WIDAS TEST RESULTS.

Table 7-1 shows the materials and test methods for which comparative data was produced.

TABLE 7-1. COMPARISON OF MATERIALS AND TEST METHODS

Material	EAB Tests	Indenter Tests	WIDAS Tests
PVC	X	X	
PVC G-N		X	
XL-ETFE	X	X	
Composite TKT		X	
Polyimide INST		X	X
Polyimide Power		X	X

Ideally, there would be an independent testing procedure done for all of the six wire types for this study for comparison with the Indenter modulus values. However, no independent test method was available for PVC G-N or Composite TKT.

7.1 ELONGATION-AT-BREAK VERSUS INDENTER RESULTS.

Figure 7-1 compares the EAB values with the Indenter values for PVC as aging time increased, and figure 7-2 shows a cross plot of modulus versus EAB values. These plots show that there is good correlation between PVC modulus readings and EAB, with the exception of the EAB data at the 6-week aging value, which is believed to be an anomaly. The two curves on figure 7-1 are in reverse direction because modulus values increased while EAB values decreased with aging. The results confirm the ability of the Indenter to track the change occurring in PVC as it aged. Even though the EAB data at 6 weeks aging was not consistent with the known behavior of PVC, the Indenter data accurately determined that the material had aged more since the measurements taken at 4 weeks of aging.

Figure 7-3 compares the EAB values with the Indenter values for XL-ETFE as aging time increased, and figure 7-4 shows a cross plot of modulus versus EAB values. These plots show that there is some correlation between XL-ETFE modulus readings and EAB, but the correlation was not as good as it was for PVC. The correlation results were affected by the decrease in modulus values from the 9-week to the 12-week aging level. The most obvious reason for the lack of good correlation is that the Indenter values did not change much throughout the entire aging sequence. The variation of modulus values is only about 4% of the total modulus value at any point of aging; thus, there was no real change above what is assumed to be the accuracy range of the Indenter.

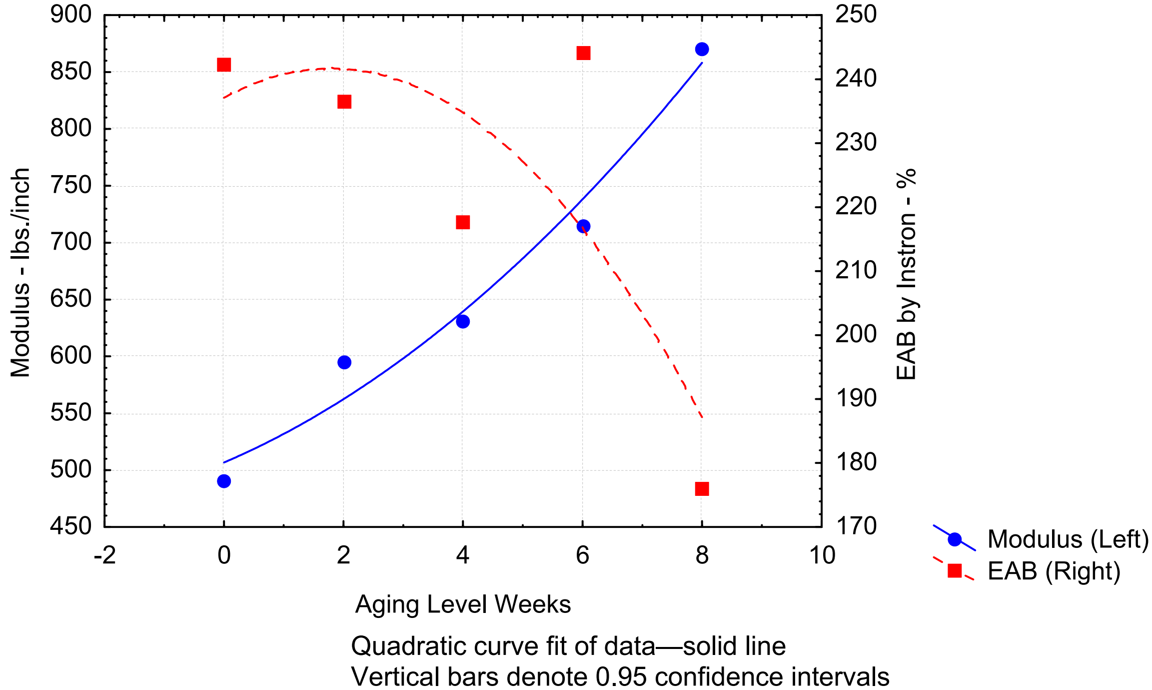


FIGURE 7-1. PVC—MODULUS AND EAB VERSUS AGING

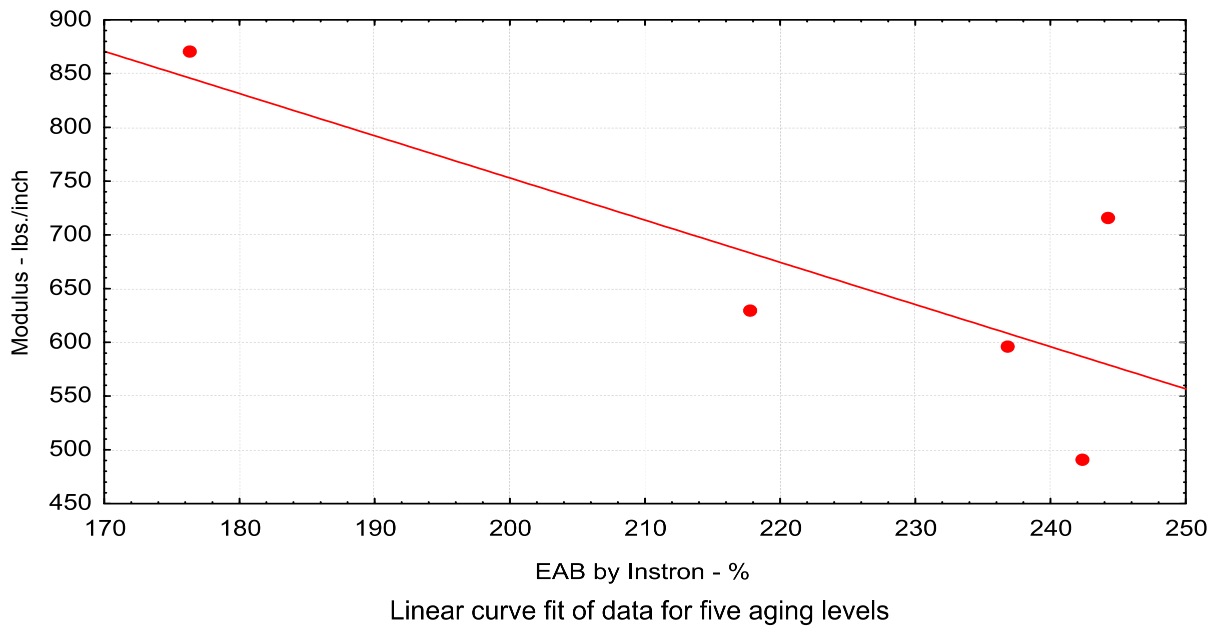
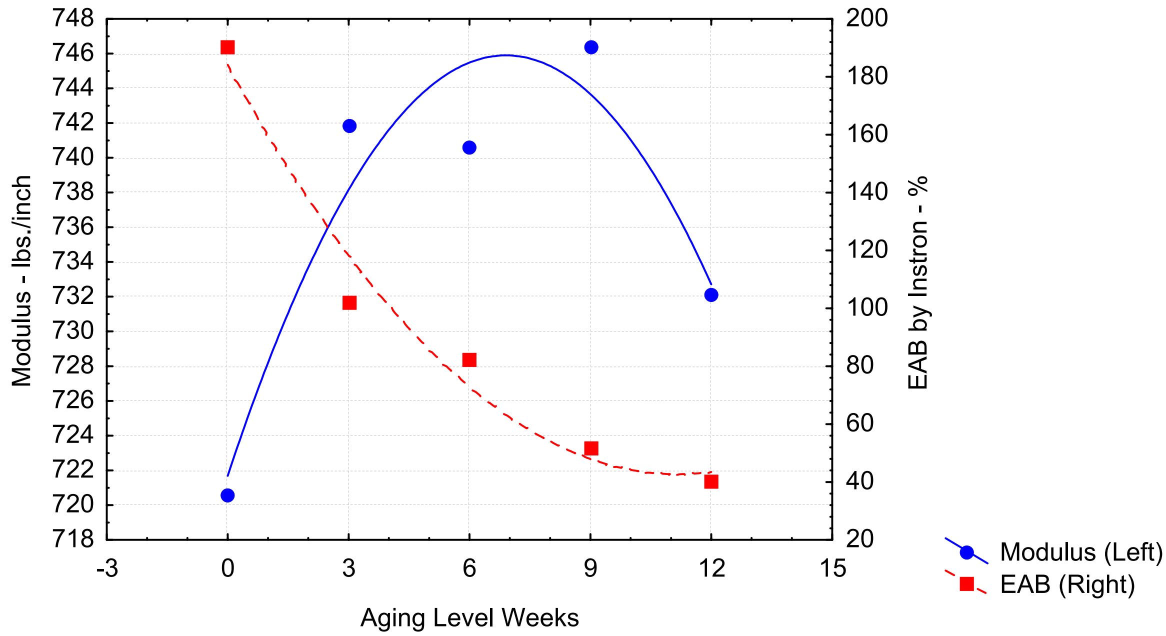
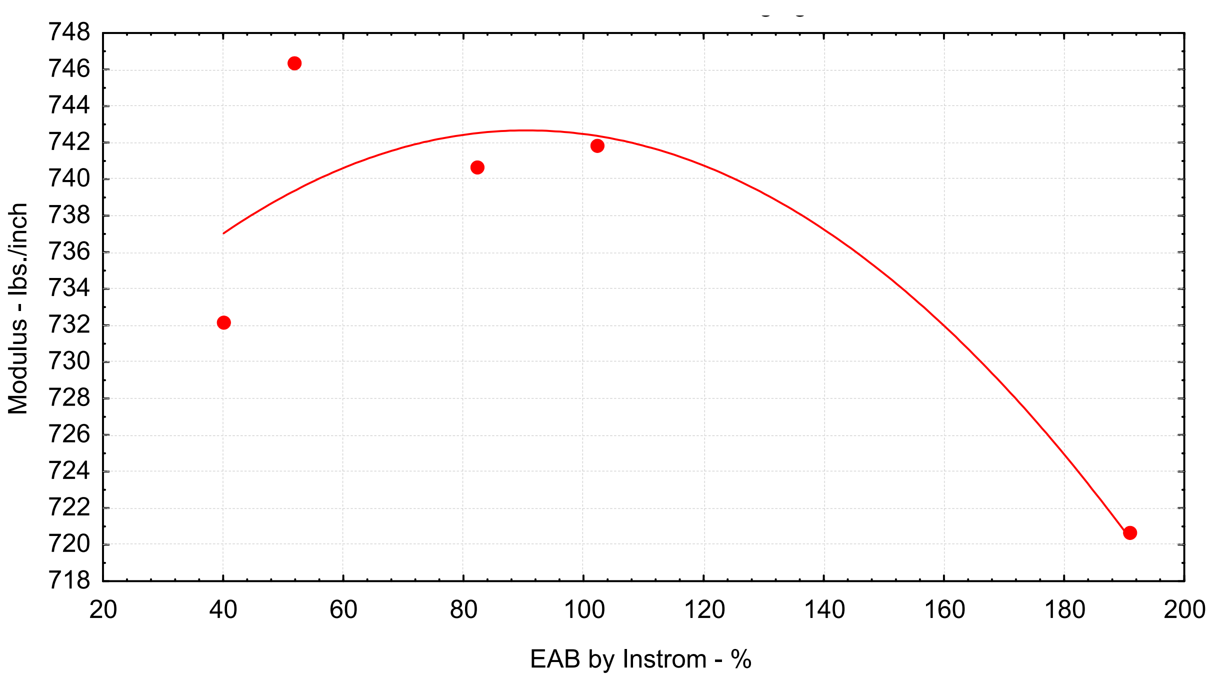


FIGURE 7-2. PVC—MODULUS VERSUS EAB



Quadratic curve fit of modulus—solid line
Quadratic curve fit of EAB values – dotted line

FIGURE 7-3. XL-ETFE—MODULUS AND EAB VERSUS AGING



Quadratic curve fit of data for five aging levels

FIGURE 7-4. XL-ETFE—MODULUS VERSUS EAB

7.2 WIRE INSULATION DETERIORATION ANALYSIS SYSTEM VERSUS INDENTER RESULTS.

Figure 7-5 compares the WIDAS average hour fail time values with the Indenter values for Polyimide INST as aging time increased, and figure 7-6 shows a cross plot of modulus versus WIDAS average hour fail time values. These plots show that there was good correlation between Indenter and the WIDAS data for Polyimide INST. The two curves on figure 7-5 show reverse direction because the modulus values increased while the WIDAS average hour fail time values decreased with aging. The results indicate that the Indenter is able track the change occurring in Polyimide INST as it ages.

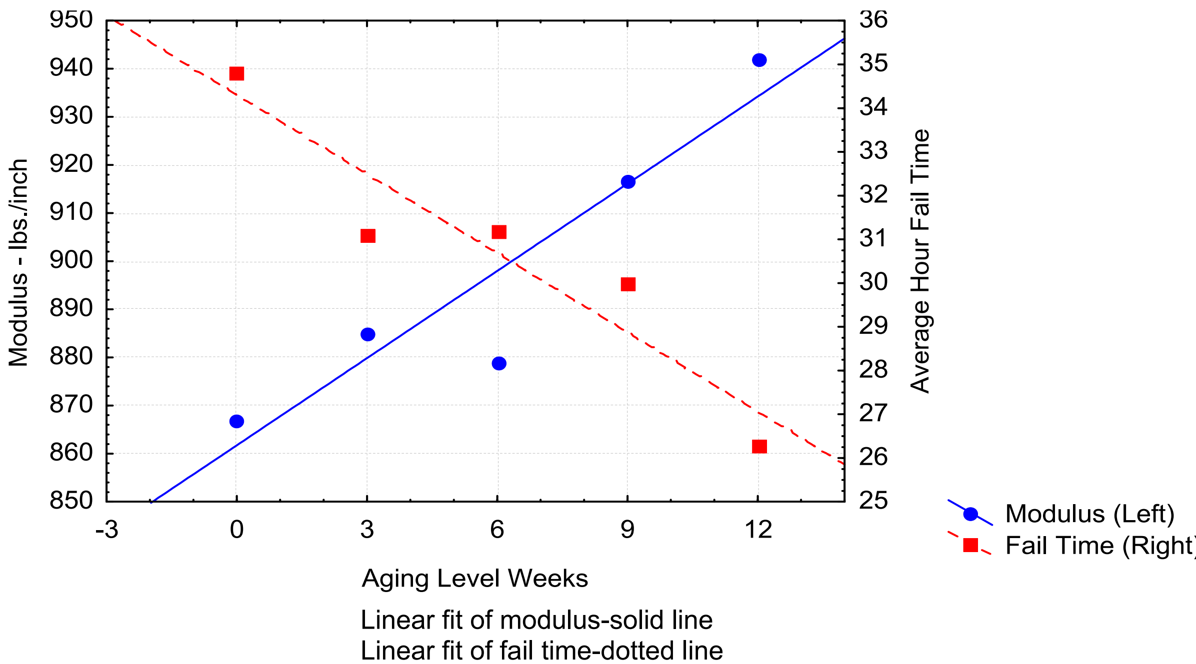
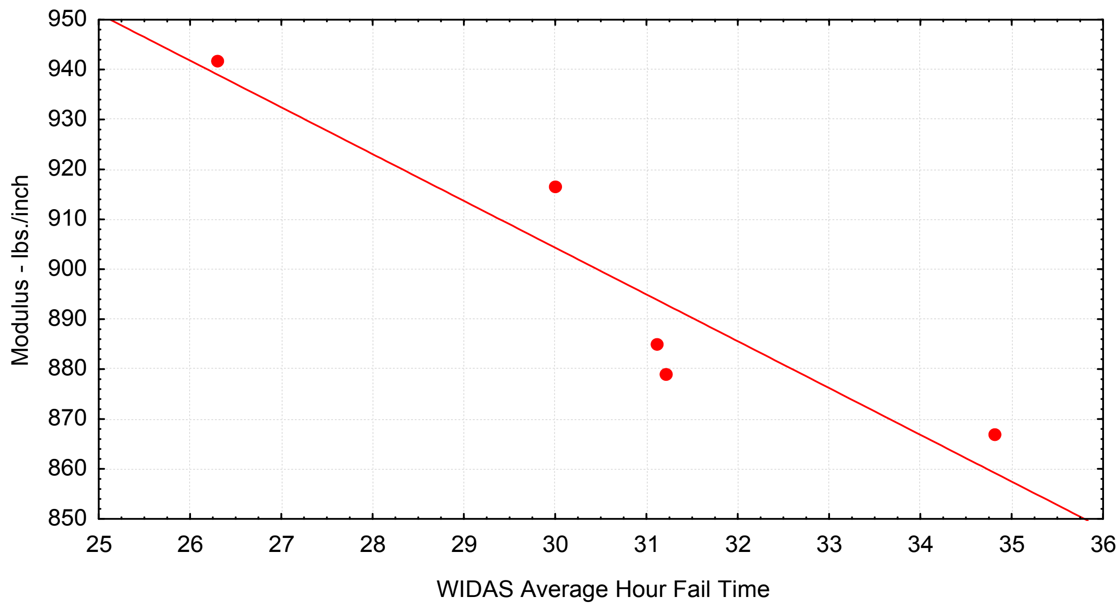


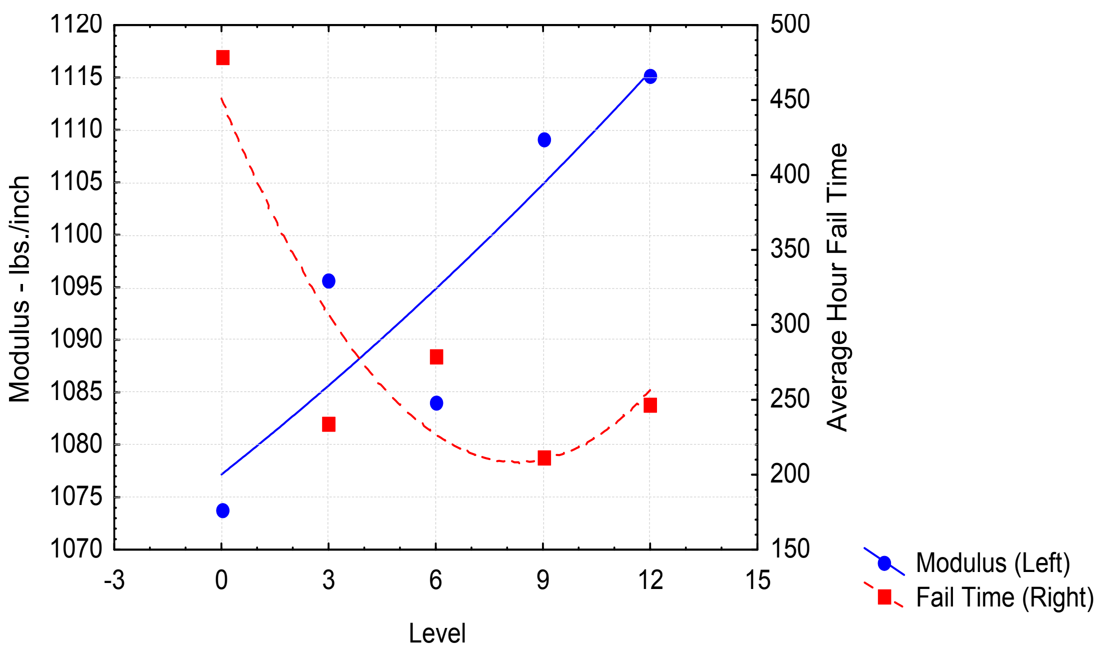
FIGURE 7-5. POLYIMIDE INST—MODULUS AND WIDAS FAILURE TIME VERSUS AGING

Figure 7-7 compares the WIDAS average hour fail time values with the Indenter values for Polyimide Power as aging time increased, and figure 7-8 shows a cross plot of the modulus versus the WIDAS average hour fail time values. These plots show that there is some correlation between Polyimide Power modulus readings and the WIDAS average hour fail time, but the correlation was not as good as it was for Polyimide INST. The correlation results were affected by the decrease in modulus values from the 9-week to the 12-week aging data.



Linear curve fit of data for five aging levels

FIGURE 7-6. POLYIMIDE INST—MODULUS VERSUS WIDAS FAILURE TIME



Quadratic curve fit of modulus –solid line
Quadratic curve fit of fail time-dotted line

FIGURE 7-7. POLYIMIDE POWER—MODULUS AND WIDAS FAILURE TIME VERSUS AGING

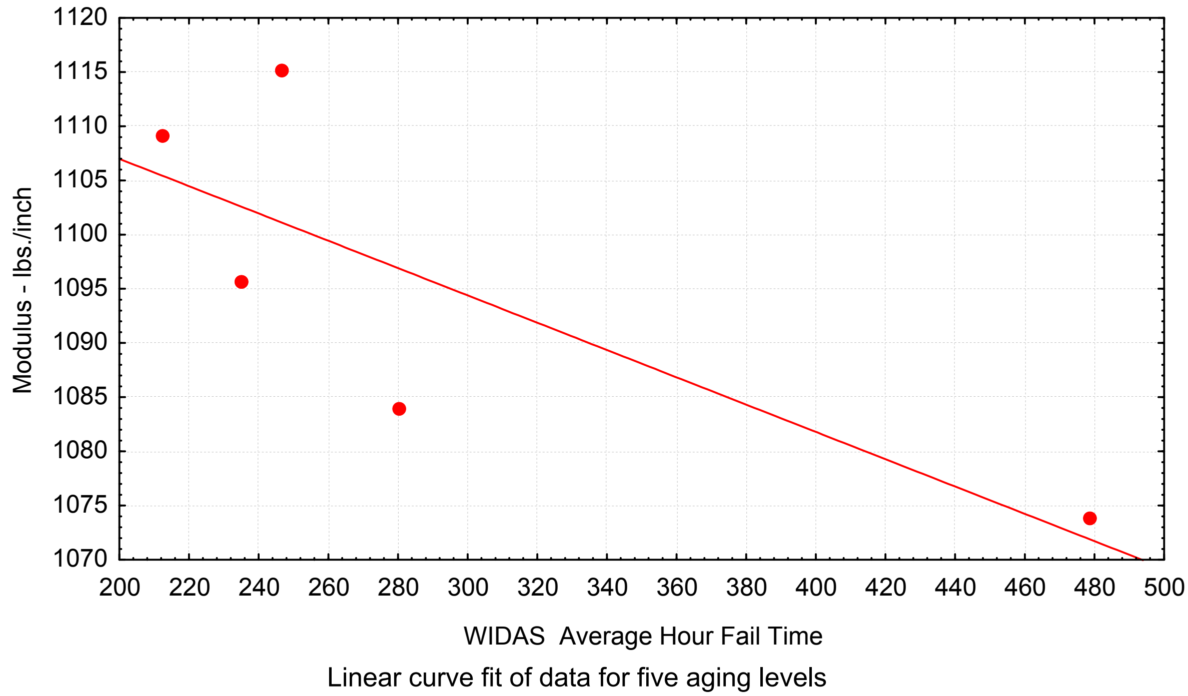
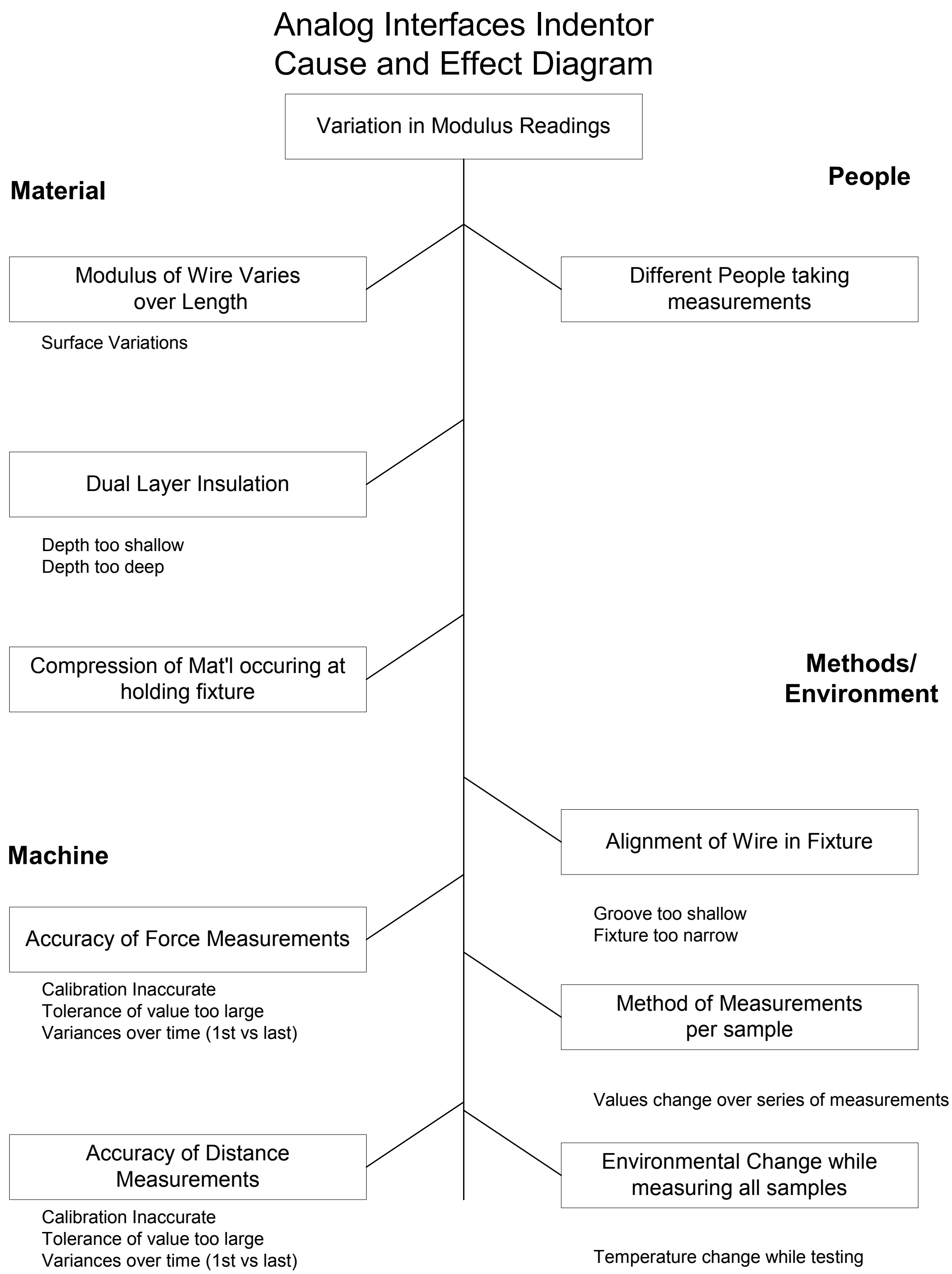


FIGURE 7-8. POLYIMIDE POWER—MODULUS VERSUS WIDAS FAILURE TIME

The WIDAS test involved wrapping samples around a test mandrel, which introduced stresses in addition to those seen by the Indenter. The samples received had a V or U shaped bend in them. It was stated that in order to fit the samples in the oven for the aging process, they had to be hung over a bar. When the samples were wrapped around the mandrel, a direction of wrap that conformed to the orientation of the bend was used. When Indenter testing was done on the samples, testers were instructed to avoid taking measurements in the section of the bend so as not to introduce new stresses.

8. TESTING VARIABLES.

The following diagram identifies four categories (material, people, machine, and methods/environment) that could influence the Indenter modulus values.



8.1 MATERIAL.

Ideally, the only variation in the readings would be introduced by changes in the material from the aging process. However, even in the unaged control samples, there were some variations in the Indenter readings. Thus, it was reasonable to assume that there were minor variations in each material from the manufacturing process. Based on discussions with Boeing, there were no apparent variations introduced in the aging process caused by factors such as position in the aging ovens or uneven temperatures.

A comparison of the materials and methods of construction of the six insulation systems may also provide some insight to explain variations:

Material	Layers	Construction
PVC	1	Extruded
PVC G-N	3	Extruded/braided/extruded
XL-ETFE	2	Extruded /extruded
Composite TKT	2	Wrapped/wrapped
Polyimide INST	2	Wrapped/wrapped
Polyimide Power	2	Wrapped/wrapped

The insulation systems that were expected to exhibit the least variation from average values as aging increases were systems that had the least number of layers and whose constructions are absolutely uniform. Therefore, PVC and XL-ETFE were the primary candidates. PVC performed as expected, but XL-ETFE did not (and the reason is not apparent).

The insulation system that was expected to exhibit the most variation would be one that had multiple layers of different construction, i.e., PVC G-N. A different aging effect maybe present with this wire type; for example, the nylon insulation may become more brittle at first, leading to rising modulus readings. The glass weave may also provide additional compliance that could effect the readings. The PVC insulation also ages but at a different rate since it is the inner protected layer. If the outer nylon layer were to begin degrading to the point where cracking or other significant aging effects are present, then the Indenter might sense more of the PVC effects since the nylon may not contribute as much to the modulus reading. These combined effects might lead to an initial increase in modulus readings followed by a decrease, and finishing with a more rapid increase to the end of service life of this wire. This explanation is one possible scenario on how to interpret these results. More analysis and testing are needed. The aging effects with other constructions might also behave in a similar fashion.

8.2 PEOPLE.

Each tester did their testing over a period of approximately 4 days, and the total elapsed time from the beginning of work by tester 1 to the end of work by tester 3 was 5 weeks. Two types of tester variations can be evaluated by comparing how the average value of a given tester compares to the other testers, and how the 0.95 confidence levels compare among the three testers; that is, is the height of the line similar among the three testers?

The figures showing individual tester variations for the six material types are shown in sections 5.1 though 5.7. A summary of the evaluations for each of the six materials is as follows:

- PVC—There was small tester-to-tester variation in modulus and relaxation averages and 0.95 confidence level. No tester is consistently higher or lower.

- PVC G-N—There was significant variation among testers with tester 2 typically higher than tester 1, and tester 3 higher than both the others. There was no apparent reason for the variation. If tester 3 had continued to be higher than the other two for the remainder of the wire type tests, then it might be explained by the Indenter being out of calibration. But since all testers tested the wires in the same order and there were four wire types tested after PVC G-N and the readings of tester 3 were not the highest in those cases, then the calibration was not a factor.

- XL-ETFE—Tester 2 was consistently higher than the other two testers on the modulus. Readings are grouped closer on the relaxation values.

- Composite TKT—Grouping of averages was generally good for both modulus and relaxation, but individual 0.95 confidence levels showed a big range.

- Polyimide INST—Modulus grouping was good for aging levels of 0, 6, and 12 weeks. There was divergence in the readings for levels 3 and 9 weeks. The relaxation values showed moderate grouping.

- Polyimide Power—Modulus readings showed poor consistency among the three testers. The relaxation readings were mixed; they were good at some aging levels and poor at others.

Table 8-1 shows a summary of the consistency among the three testers. A rating system (A, B, or C) was established using the following basis:

- A—Averages for each tester were very close

- B—Each tester's average consistently fell within the other tester's 0.95 confidence interval but grouping was not as good as A

- C—Some significant variation in averages among the three testers

TABLE 8-1. RATING OF CONSISTENCY OF READINGS AMONG THREE TESTERS

Wire Type	Modulus Averages Grouping	Relaxation Averages Grouping
PVC	A	A
PVC G-N	C	A
XL-ETFE	C	B
Composite TKT	A	A
Polyimide INST	B	B
Polyimide Power	C	C

The excellent grouping of the three testers for PVC data indicates that the capability of the Indenter system to obtain valid data is not dependent on the experience or technical background of the person performing the tests. The cause of the variations among testers for some of the other materials is not apparent from the data obtained during this research. Since some of the materials show wide variations in readings obtained by the same tester, the experience of the tester does not seem to be a factor. Also, for those materials whose total range of modulus values from all aging levels is less than 10% of the lowest reading can be explained as being within the assumed accuracy range of the Indenter.

Another possible explanation can be changes in calibration over the period of time of the testing. However, the force calibration was checked after tester 2 had completed all tests, and the system was found to be in calibration.

8.3 INDENTER.

Some system variations can affect the results, such as changes in mechanical properties of the CCA, changes in performance of the force sensor, and changes in electrical performance of force sensor-conditioning electronics. As with any mechanical system, wear and stress can lead to changes in performance over time. The CCA was designed to allow normal wear and minimize its effects by using preloading and strong mechanical components, which are mounted in a rigid support structure. The design ensures consistent mechanical operation.

The Indenter uses both a force sensor and motor encoder to gathered the modulus and relaxation measurements. The force sensor is calibrated using various size National Institute of Standards and Technology (NIST)-traceable weights in a range from 0 to 3 kg, which ensures that it is calibrated and its operation verified both within and above its typical testing range. The force sensor has its own protection mechanism against an over-force condition, and additional design elements have been added to improve performance and protection. The force sensor-conditioning electronics are high-quality components with low drift properties. The published accuracy of the sensor is 0.1% of full scale.

The probe position and velocity is tracked by a motor encoder that generates an accurate series of pulses with each rotation of the motor. Each pulse represents a specific degree of rotation of the motor armature. The calibration procedure calibrates average velocity by determining the amount of time required for the probe to move a specific distance, and the program then calculates a correction factor for each velocity used in testing. The effects of thousands of mechanical cycles have not been determined, but regular calibrations will detect subtle changes.

8.4 METHODS AND ENVIRONMENT.

The design of the V groove in the CCA provides for consistent, firm seating of the wire as long as the tester takes normal precautions to ensure that the wire is not cocked (misaligned) in the fixture.

The testers made measurements at random positions along the length of the wire samples and rotated the wire between tests (some rotation usually occurs automatically when the wire is positioned for a new test). The testers were not told how to hold the CCA during testing. Separate testing indicated that measurements are not subject to the position in which the CCA is held during testing.

A tester can cause faulty data to be taken. This occurred during the portion of the test when relaxation data was being taken, where the tester opened or released pressure on the wire clamping before the Indenter was finished making the measurement. This type of error was easily recognized in the testing software plot.

All Indenter testing was done under normal room temperature and humidity conditions. Thus, environmental change is not a contributing factor to variations in modulus values.

9. INDENTER POLYMER AGING MONITOR MODEL 3 HARDWARE AND SOFTWARE DESIGN.

The Indenter Polymer Aging Monitor Model 3 (IPAM3) system consists of the hardware and software used in obtaining the Indenter readings described in section 5. The IPAM3 design objectives were as follows:

- Make the system truly portable (small, light, and battery powered).
- Provide a tool that can be used in aviation operational and maintenance environments.

The baseline design for the IPAM3 was a system that is used by the nuclear industry where cables up to 2.5 inches in diameter can be tested. To meet the needs of the aircraft industry, the IPAM3 had to be able to clamp on the much smaller diameter wires commonly found in aircraft. Since it is a tool used to test wires without removing them from an aircraft, it also had to be able to access these wires where they are installed.

9.1 SYSTEM DESCRIPTION.

All major components in the IPAM3 are a new design. Figure 9-1 shows a block diagram of the IPAM3, and figures 9-2 and 9-3 show all the system components clipped to a carrying belt and ready for use. The individual components of the new design are discussed in sections 9.1.1 through 9.1.6.

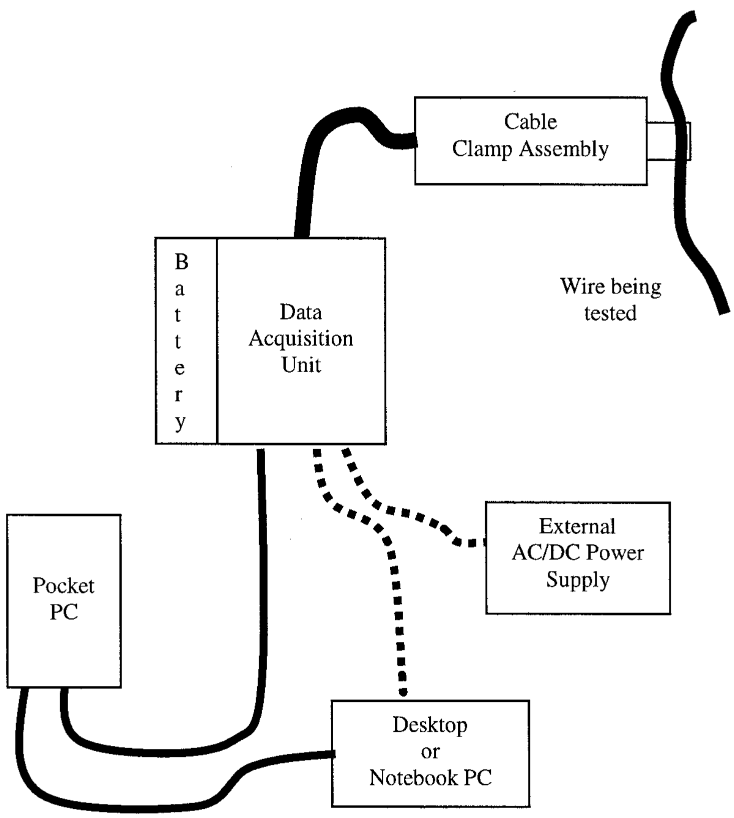


FIGURE 9-1. BLOCK DIAGRAM OF THE IPAM3 SYSTEM

FIGURE 9-2. THE IPAM3 COMPONENTS ON BELT

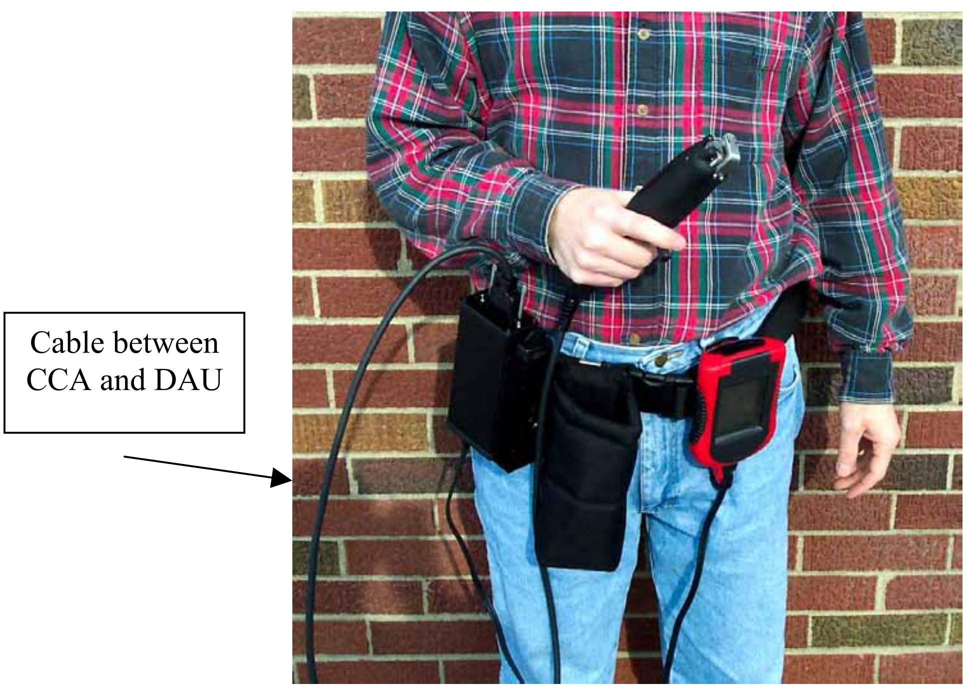


FIGURE 9-3. THE IPAM3 COMPONENTS ON BELT WITH THE CCA IN HAND

9.1.1 Cable Clamp Assembly.

The CCA is the hand-held device that clamps over the wire being tested. The clamp head was originally designed so that wires as small as #20 AWG would be securely held during testing, but the head itself was large. The entire CCA is now small enough so that it can access wires where they are installed in aircraft. Figures 9-4 through 9-7 shows the new CCA. The redesign of the CCA was a major task. An outside engineering firm that specializes in custom product design was used. As a starting point, it was decided to use the same motor and force sensor used in the nuclear Indenter model, because they were proven to give good results. The objective then was to incorporate these components into a design that had the ability to clamp on small wires and was a lightweight, smaller, and more ergonomic hand-held device.

FIGURE 9-4. CABLE CLAMP ASSEMBLY

FIGURE 9-5. CABLE CLAMP ASSEMBLY WITH KEYPAD

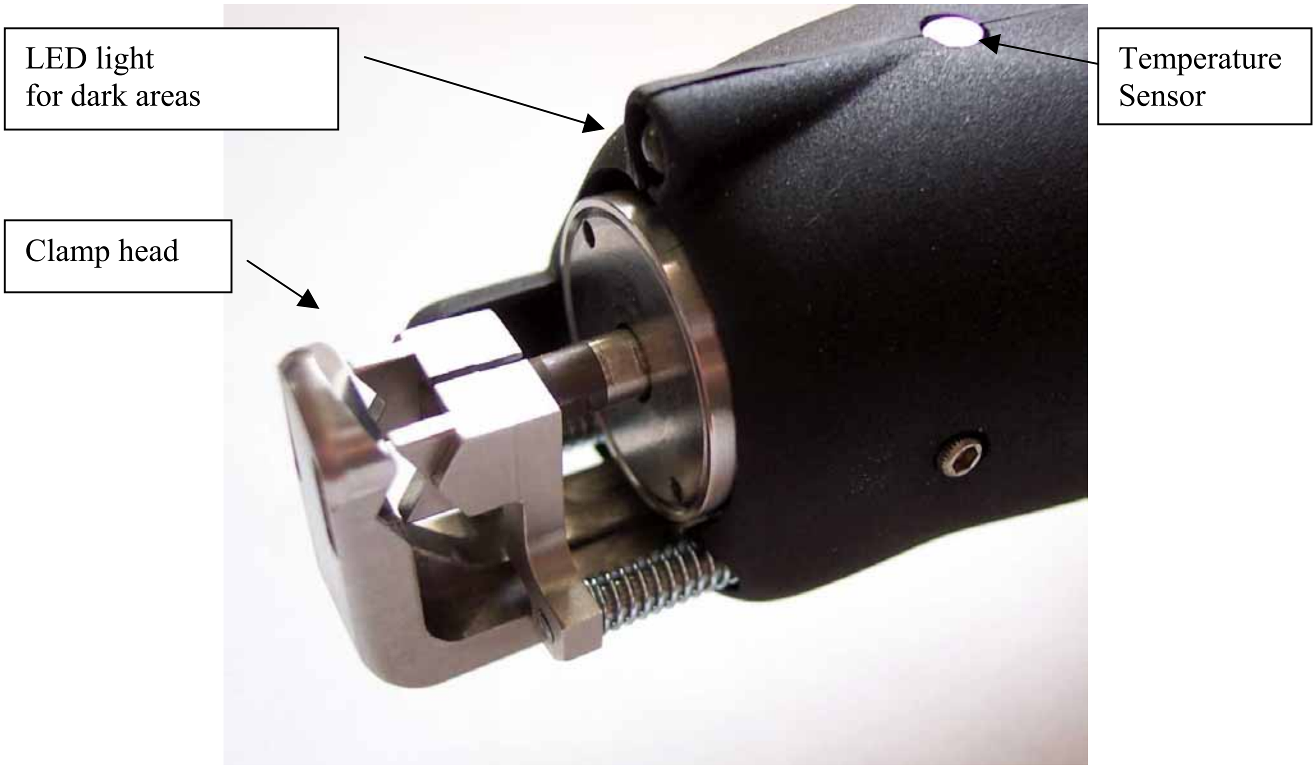


FIGURE 9-6. CABLE CLAMP ASSEMBLY CLAMP END

FIGURE 9-7. CABLE CLAMP ASSEMBLY WITH WIRE INSERTED

Design for lower cost and easier manufacturing was also a major consideration. Thus, the housing is now a molded-plastic part, and internal parts were designed so they could be tooled in the future to achieve cost savings.

The CCA includes a temperature sensor that can be used for recording the ambient temperature during testing. It also includes a light emitting diode (LED) to provide some light at the testing point to facilitate testing in low light conditions. A provision has been made in the housing to incorporate a linear variable differential transformer for measuring deformation, if needed in the future.

Control of testing is done by a keypad on the CCA (figure 9-5) that provides buttons for:

1. Initiating a scan
2. Aborting a scan
3. Turning on the LED light

LED's on the keypad show

1. Power ON
2. Scanning light illuminates during data taking

9.1.2 Data Acquisition Unit.

The data acquisition unit (DAU), which includes a removable battery, holds the data acquisition electronics and includes various connecting and control hardware on the end panels. A newly designed surface-mount printed circuit board with the latest generation components were needed to meet the size and weight objectives. The Indenter model designed for the nuclear industry contained PC boards that were large and used many older generation components. Thus, reducing the existing DAU electronics to the size needed for this portable application was a major task that required a completely new design of all the electronics. It was mandatory to move to surface-mount technology to meet the system objectives. The complexity of the circuit and the overall package size limitations required the use of two boards. The original boards measured 8.5 by 9 inches; the two new boards measure 6.375 by 3 by 1.25 inches. The boards were designed as six-layer boards to provide for the necessary routing of traces and ground planes for signal integrity and noise reduction. Figures 9-8 through 9-10 show the redesigned DAU unit with the new boards.

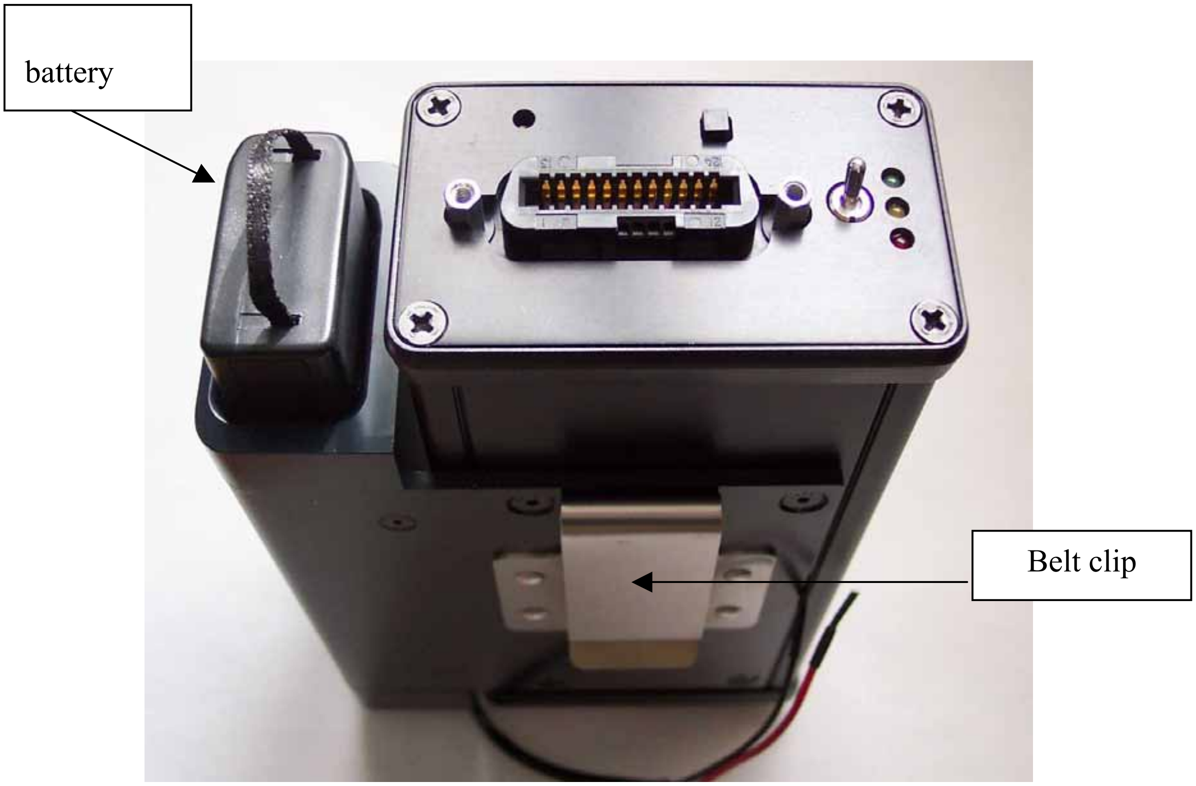


FIGURE 9-8. DATA ACQUISITION UNIT WITH REMOVABLE BATTERY

FIGURE 9-9. TOP PANEL OF DAU

FIGURE 9-10. BOTTOM PANEL OF DAU

9.1.3 Pocket PC.

The Pocket PC is the device that will be used in the field to control the testing and save the test data for later transfer to a host PC. The power, size, and flexibility of the latest generation of Pocket PCs made them an ideal choice for this application. A rugged carrying case is included to give protection from the environments encountered in aircraft testing.

People that regularly perform aircraft testing were asked if they had any problems using a Pocket PC and what factors should be kept in mind in using this approach. The feedback indicated that using a Pocket PC was acceptable provided that it was both easy to use and rugged. It was decided to use a Pocket PC because of the many features and flexibility this approach offered. Advancements in Pocket PC capabilities and the development of Pocket PC Windows software have made this product a very powerful tool. The Pocket PC selected for use with the IPAM3 was the Hewlett-Packard (HP)/Compaq iPAQ Pocket PC. This product offered the best features as well as good developer support and a competitive price.

A rugged case (offered by HP as an accessory) was selected because it provides good dust, moisture, and shock protection. The screen of the Pocket PC is protected by a plastic layer in the rugged case. Selecting options on the Pocket PC screen is done by finger touch or stylus. The rugged case includes a metal clip for inserting over a belt. Figure 9-11 shows the Pocket PC in the rugged case.

FIGURE 9-11. POCKET PC IN RUGGED CASE

<u>9.1.4 System Connections</u>.

The IPAM3 block diagram (figure 9-1) shows how the system components are connected.

The cable between the CCA and the DAU used in the Indenter designed for the nuclear industry was big, bulky, and heavy (outside diameter 0.625 inch). It has now been replaced by a new custom cable (figure 9-3) which is light and flexible (outside diameter 0.305 inch).

The DAU is connected to the Pocket PC where test data is stored for later transfer to a desktop or notebook host PC.

The dotted lines in the block diagram (figure 9-1) show optional connections. When using the IPAM3 in a laboratory or where alternating current (ac) is available, the system can be powered by an external ac/direct current (dc) power supply. The DAU can also be connected directly to the desktop PC, thereby bypassing the Pocket PC when it is used in a laboratory setting.

9.1.5 Belt and Pouch.

In order to make the system easy to use in the field, a belt is provided with provision for carrying and accessing the system components. The following items are each fastened to the belt by their own clip:

- The Pocket PC rugged case
- DAU
- A cloth pouch containing the CCA

When taking a test, the operator will remove the Pocket PC from the belt and initiate the test-taking mode. The Pocket PC will then be replaced on the belt. Next, the CCA will be removed from its pouch and tests will be taken. A keypad on the CCA will be used to start each test. The DAU is not removed from the belt during data taking. Figures 9-2 and 9-3 show the system components clipped to the belt.

9.1.6 Power.

The criteria for selecting a battery included balancing size, weight, capacity, and ease of access for replacing the battery. The battery selected for the system is an off-the-shelf rechargeable Lithium Ion Smart Battery. The battery is 5.75 by 1.5 by 0.75 inches and weighs 7 ounces. The battery capacity is 3600mAh, which should provide 8 hours of operation, depending on the number of tests taken. The battery is mounted in a bracket attached to the DAU enclosure and is easily removed for field replacement if necessary. There is a cutout in the battery bracket that provides access to the battery capacity indicator on the battery. An external battery charger is included with the prototype system. Figures 9-12 and 9-13 show the battery and the charging unit. When the Indenter system is used in the laboratory, or wherever an AC outlet is available, the system can also be powered by an external ac/dc power supply.

FIGURE 9-12. REMOVABLE BATTERY

FIGURE 9-13. BATTERY CHARGER

9.1.7 Calibration.

There are two calibrations that have to be done on the system. The first calibration is for the force sensor. This calibration is done by placing NIST-certified stainless steel test weights on the force sensor using a custom calibration fixture. A software calibration program calculates an adjustment factor that is applied to the force sensor readings.

The second calibration involves the velocity, which is calibrated by using a dial indicator and a stopwatch. A calibration fixture, dial indicator, and three weights are included with the prototype system. The person performing the calibration enters values into the calibration software, which then calculates an adjustment factor and applied to the velocity. Calibration would typically be done in a laboratory or office where the fixture is clamped to a table. A full calibration involving both force and velocity, which can be performed in about 15 minutes, is required every few months.

9.2 SOFTWARE.

9.2.1 Data Acquisition Unit Firmware.

The software that operates in the DAU is written in C language and controls all aspects of the test taking. Test-taking parameters of maximum force and velocity were standardized in the IPAM3 at 2 pounds and 0.2 inches/minute, respectively. The maximum force is the value at which the test probe movement into the wire insulation stops and then retracted.

9.2.2 Pocket PC Software.

The Pocket PC Software includes the screen display, the commands that control test taking, and the configuration and storage of setup and test data.

9.2.3 Desktop PC Software.

This software is a modification of the previous Indenter software. All the field test results are stored in the desktop PC. The desktop PC software functions also include viewing of test data, configuring setup information, calibration, and the ability to import and export this data.

9.3 INDENTER TEST-TAKING PROCEDURE.

The following summary describes the eight steps involved in obtaining data with the Indenter in the field:

1. The operator enters, or selects from a drop down list on the Pocket PC, data about the location and wire being tested (such as tail number of aircraft, location on aircraft, wire type, and circuit).

2. The operator presses the Start Test button on the Pocket PC.

3. The Pocket PC is then put back on the belt or placed on a structural member or convenient surface (to view the screen if desired), and the CCA is removed from the belt.
4. The CCA jaw is opened to clamp over the wire to be tested (figures 9-6 and 9-7).

5. The SCAN LED flashes, indicating that the unit is ready. The operator presses the SCAN button on the CCA to start the test. The SCAN LED turns on, indicating the test is underway. A single test cycle typically takes approximately 10-15 seconds. When the SCAN LED turns off, the test is complete.

6. The operator moves the CCA to a different test location on the same wire and presses the SCAN button again to initiate a new test. Typically ten individual tests are taken to characterize a given wire location.

7. When these tests are complete, the CCA is replaced in its pouch and the Pocket PC is removed from the belt. The operator may add notes and observations and presses the Save Session button on the Pocket PC screen, saving all the test data and configuration/setup information in a date-and-time-stamped file. Completion of this cycle of the ten tests takes approximately 5 minutes.

8. The tester then moves to the next location on the aircraft and repeats the steps above.

10. CONCLUSIONS AND RECOMMENDATIONS.

The results of the EAB and WIDAS test were compared to the Indenter results to determine a correlation between them. Table 10-1 shows the correlation between the test results and the indenter results for each type of insulation.

TABLE 10-1. SUMMARY OF CORRELATION BETWEEN TEST METHODS

Material	Correlation Between EAB and Aging	Correlation Between Indenter and Aging	Correlation Between WIDAS and Aging	Correlation Between Indenter and EAB	Correlation Between Indenter and WIDAS
PVC	Good	Very good	---	Good	---
PVC G-N	---	Moderate	---	---	---
XL-ETFE	Good	Cannot be determined	---	Moderate	---
Composite TKT	---	None apparent	---	---	---
Polyimide INST	---	Good	Good	---	Good
Polyimide Power	---	Cannot be determined	Slight	---	Moderate

10.1 CONCLUSIONS.

Based on a comprehensive review of all the data, the following conclusions can be stated:

- The accuracy of the data obtained by Indenter testing is not dependent on the experience of the person performing the test.
- The new Indenter is suitable for testing small wires installed in aircraft and produces reliable data.
- The indenter results correlate well with other methods, but not all methods correlated with the different insulation specimens.
- The general shape (convex/concave) of the curves fitted to the data plots for Indenter modulus and relaxation values are typically the same; the application of relaxation data to material aging must be evaluated further.
- The Indenter data for some aged materials fell within the assumed accuracy of the Indenter and showed no trends. These were materials for which there is no comparison data available from other testing methods. Since the amount of aging degradation resulting from the aging protocol is unknown, it cannot be determined if the Indenter

results indicate that the material actually was not aged significantly or if the Indenter measurements are not suitable for that type of material.

10.2 RECOMMENDATIONS.

Based on the data obtained and experience gained in performing this research, recommendations for additional research in the following topic areas are presented:

- Relaxation Method—Investigation of Time Shift
- Comparison of Indenter and Wire Insulation Deterioration Analysis System (WIDAS) Data at Bends in the Wire
- Additional Oven Aging of Selected Insulation Materials
- Measuring Deformation on Hard Wires
- Simplified Field Calibration Method
- Inclusion of Indenter Testing in Other Sponsored Research
- Nondestructive Testing

10.2.1 Relaxation Method—Investigation of Time Shift.

The calculation of a relaxation value does not involve deformation measurement. If it becomes difficult to measure deformation to the accuracy needed, then using the relaxation value may become significant. The relaxation value calculation currently uses two force measurements after the peak force is reached (one at 2 seconds and one at 4 seconds). Using force data at different times (from 1 to 7 seconds) might give more meaningful information. This Indenter research was the first one to obtain extensive relaxation data; thus, it provides an excellent opportunity to determine which one of many possible data combinations provides the most meaningful understanding of what is occurring in the material as it ages and how to monitor it.

10.2.2 Comparison of Indenter and WIDAS Data at Bends in Wire.

WIDAS testing involved winding the wire samples around a mandrel. For the Indenter testing, the measurements were avoided being taken purposely in the areas of the wire bend. Electrical failure is anticipated to occur at the point of mechanical failure of the insulation, and the bend area is the location of the highest mechanical stress. Additional work can be done by repeating the Indenter measurements on all specimens that were WIDAS-tested but require that all measurements be taken in the area of the bends. The new Indenter data would then be compared to the previous measurements to determine if location of the measurement influenced the results of the original research.

10.2.3 Additional Oven Aging of Selected Insulation Materials.

The six wire types were all aged at a temperature that was 20°C above the maximum temperature rating of the insulation material. The selection of the temperature was not related to a specific end-point or percent of anticipated total life of the material. Several of the insulation systems are designed to operate at very high temperatures for very long periods of time. Examination of the data obtained during this research suggests that some of the materials did not experience much aging during the 12-week aging exposures. Thus, very little change would be seen in the Indenter data. It is important to have the Indenter (and other values) on wires, which were commonly agreed on, that are at an aging level that is near the end of life. Non-PVC wire samples from this test have to be aged to either twice or triple the levels that they already were aged and additional Indenter data has to be obtained.

10.2.4 Measuring Deformation on Hard Wires.

In all Indenter testing performed prior to this study, deformation values were typically in the 0.010- to 0.020-inch range, and modulus values generally were less than 800 lb/in. In the current study, deformations in some cases were less than 0.002 inches and modulus values for some of the hard materials exceeded 1000 lb/in. The system currently used to measure deformation is based on reading a decoder that gives the number of turns of the motor moving the probe tip. Investigation of hard materials during this research revealed that accumulated deviations in the drive train mechanism plus force sensor deflections resulted in the probe tip actually moving less than the amount calculated from the motor encoder. This finding is significant at the higher modulus numbers (smaller deformations) of some of the wires that were tested. It was estimated that the deformation accuracy of the present system is approximately 0.001 inch. Thus, Indenter testing of very thin sections of hard materials could produce modulus values that do not reflect the actual aged condition of the material.

The modulus is calculated as Delta F divided by Delta X. Delta F is the force difference, and Delta X is the deformation difference between two points on the cross plot of force versus deformation on the inward movement of the Indenter probe. In the testing that was done in this study, the test parameter peak force was set to stop on inward movement of the probe at a 2-lb force. The two points used to calculate Delta F and Delta X were selected as 75% and 25% of the peak force; that is, 1.5 lb and 0.5 lb. Therefore, Delta F was always 1.0 lb.

Because of the smaller deformations involved in the higher modulus, significant time was spent on studying the displacement accuracy. The displacement is based on the number of turns of an encoder on the end of the motor driving the probe into the material. In studying the mechanical drive train, it became apparent that there are accumulated deviations in the linkage from the encoder up to the probe tip. Thus, the calculation of what the probe tip should have moved based on the number of turns of the motor did not necessarily represent the actual position of the probe tip as it moved into the material.

It was estimated that the present measurement system is not capable of resolving deformations greater than 0.001 inch. Table 10-2 shows the effect on modulus values of a change in 0.001 inch. If displacement readings are in the 0.010 inch range, then a change of 0.001 inch affects the modulus reading by 10%. However, if displacements are in the 0.001-inch range, then a change of 0.001 inch results in a change in modulus of 50%. If the displacement is in the range of 0.002 inch, then in order to see a modulus change of around 10% one would have to be able to resolve a deformation of 0.0001 inch.

TABLE 10-2. EFFECT OF CHANGES IN DELTA X ON MODULUS VALUES

Delta F	Delta X	Modulus
1.0	0.010	100
1.0	0.011	91
1.0	0.001	1000
1.0	0.002	500
1.0	0.0021	476

It was investigated that by using a different, more precise method of measuring deformation it was concluded that it is best to use a small linear variable differential transformer (LVDT) device connected directly at the probe tip end of the cable clamp assembly (CCA), and it can be installed inside the CCA without too much modification.

It's recommended that additional research on this topic is done to prove the accuracy of using the LVDT and making the hardware and software changes necessary to use the LVDT rather than the motor encoder.

10.2.5 Simplified Field Calibration Method.

The Indenter system needs to be fully calibrated periodically to ensure the accuracy of the data. However, calibration checks should be done every time the system is in use in the field. In order for this to be done easily when working on aircraft, the calibration method needs to be simplified.

Development of a beam standard concept to be used as a tool to determine the actual deformations has to be implemented. The beam standard could be modified to serve as a quick, easy calibration check for use in the field. It is recommended that additional research be done to fully implement the beam standard as a calibration field check as well as designing an adapter to make it easier to apply weights to the force sensor for direct calibration of the force readings.

10.2.6 Inclusion of Indenter Testing in Other Sponsored Research.

Research related to the aging of wires is currently being performed by other organizations. The new Indenter system developed in this study for testing aircraft wires can be implemented to obtain more valuable data.

10.2.7 Nondestructive Testing.

Nondestructive testing has been defined as comprising those test methods used to examine an object, material, or system without impairing its future usefulness. It has been observed that to the naked eye, there is not any observable permanent deformation of the material after the testing was completed but that a slight indentation was seen under a magnifying glass (the indentation is more pronounced on softer materials). This topic should be studied in more detail because of possible damage done to the insulation of the wire and to prove that the Indenter is a true nondestructive test tool.

APPENDIX A—MATERIALS, TEST PARAMETERS AND TEST METHODS

MATERIALS, TEST PARAMETERS AND TEST METHODS

Insulation Material or System	Referenced Specification	Max. Temp. Rating	Accelerated Aging Temp To Be Used	Duration of Aging (Weeks)	Sampling Rate (Using 1-foot Straight samples)	Test Methods
PVC	MIL-DTL-16878/1C	105°C	125°C See Note 1	8	Remove 10 samples every two weeks	E_A_B & Indenter
PVC/glass/nylon	MIL-W-5086/2C	105°C	125°C	8	Remove 10 samples every two weeks	E_A_B & Indenter
XL-ETFE (Cross-linked Tefzel®)	MIL-W-22759/42B (nickel-coated conductor)	200°C See Note 2	220°C	12	Remove 10 samples every three weeks	E_A_B & Indenter
Polyimide (Kapton®)	MIL-W-81381/12C (nickel-coated conductor) Instrument Cable	200°C	220°C	12	Remove 10 samples every three weeks. Do Indenter test on all then WIDAS test on 8	Indenter and WIDAS
Polyimide (Kapton®)	MIL-DTL-22759/86A #10 AWG Power Cable	200°C	220°C	12	Remove 10 samples every three weeks. Do Indenter test on all then WIDAS test on 8	Indenter and WIDAS
Composite (Teflon®-Kapton®-Teflon®)	MIL-DTL-22759/90A (nickel-coated conductor)	260°C See Note 3	280°C	12	Remove 10 samples every three weeks	Indenter Only

Note 1: The accelerated aging temperature will be 20°C higher than the Maximum Temperature Rating of the Wire.
Note 2: Raychem "SPEC 55" wire has a published Thermal Endurance of 200°C for 10,000 hours.
Note 3: Tensolite "Tufflite™2000" wire has a published Temperature Rating of 260°C.

General: E_A_B = Elongation-at-Break
All conductors will be size #20 AWG, except for the polyimide-insulated power cable that will be #10 AWG.
All specimens subjected to air oven aging will be straight; that is, neither coiled nor wrapped on a mandrel.

APPENDIX B—TESTING PROCEDURES

November 13, 2002

INSTRUCTIONS FOR TESTING WIRE SAMPLES

OVERVIEW:

You will be using a product called the “Indenter” to test some wire samples.

There are six different types of wires you’ll be testing. Within each type, there will be five aging levels to test with five samples in each aging level.

Your job will be to position each wire in the Indenter “jaw” and then initiate testing using the software as explained below. For each length of wire (which may be 24”, 18”, or 4-6”), you will take 10 tests. As you’ll be instructed, after each test, you’ll move the wire so a different position on the wire will be tested.

After a set of 10 tests, called a “test session”, the data will be saved and you’ll use the software to initiate a new test session on the next wire sample.

The data will be automatically taken and saved. You will not have to pay any attention to the actual numbers being obtained from the tests – the samples you’ll be given will have different readings but they’ve been arranged in a random order so the actual values will have no meaning to you.

TEST SAMPLE HANDLING INSTRUCTIONS:
It is ESSENTIAL you handle the material samples according to these guidelines so the data is valid.

You’ll be given a plastic bag with all the wires in it for one wire type. Within the bag, are five other bags representing the five aging levels you’ll be testing.

ONLY take ONE of the aging level bags out of the bigger bag at a time.

Make sure it is returned to the bag it came from IMMEDIATELY after it has been tested.

SPECIFIC INSTRUCTIONS:

Take one of the aging level bags out of the master bag for that material type. Aging level is indicated by the letter “A” followed by a number. For two of the wires – PVC and PVC-GN, the aging levels are A0, A2, A4, A6, and A8. For the other four wire types, the aging levels are A0, A3, A6, A9, and A12.

Proceed to test samples from the bags in order – i.e. A0, then A2, A4, etc.

In the aging level bag, there are 10 wires in total. We're only testing five of them so there'll be a separate bag labeled "1-5". These are the wires you'll test. Take them out of that bag and lay them on the testing cart.

TO TAKE A TEST:
From Indenter Main Menu, select "Run Test"

In the window that appears, click on "Select Project" and select the project name for the wires you're testing – i.e. PVC FAA 10/02. This name will be on the bag you're testing.

Click on tester and select your name.

Don't make any changes to the unit serial #.

Click on "OK" to proceed to the Indenter Testing window

Click on Step 1 "Select Pre-Config Test"

Select the material AND aging level that you are testing. I.e. the first wire you'll test will be PVC A0.

Click on "Notes and Description" and enter in the "Test Description" area the following information. Use CAPS.
EXAMPLE – enter: PVC A0 #1 XXX where PVC will be the material you're testing. A0 will be the aging level, #1 will be the sample number, and XXX is your initials.

The information you enter here will be on the tag on the sample you're testing. The samples will be numbered 1 through 5 – test them in order.

Once you've filled in the "Notes and Description" Click on OK

Now, click on "Auto-Restart Testing". This will tell the program to automatically move to the next test.

Position the cable being tested in the cable clamp assembly by pulling on the trigger to open the jaw and placing the wire in the jaw. Release the trigger to hold the cable.

Start at the end of the cable AWAY from the label. You'll be taking 10 tests on each wire sample and we want the testing points to be all along the length of the sample. How much you move the wire after each test depends on the cable length. This doesn't have to be exact. Get an idea of how far you should move the cable each time so the 10 tests are made along the whole length.

When you move the wire to the new test point, rotate it so we aren't always testing on the same side. This again isn't exact.

Next CLICK ON "Step 2 Start A Test"
A red message block will appear in the bottom right of the screen that says to PRESS SCAN BUTTON.

The SCAN BUTTON is on the box next to the computer keyboard.

When the SCAN button is pushed, you'll hear the motor start to move. The motor is moving a probe toward the wire being tested. It will take about 20 seconds (shorter on two of the wire types – Polyimide Power and COMPOSITE) for the probe to contact the wire. When it does, the block labeled "Test Time" will start to increase and the Red message box will disappear. Shortly after the "Test Time" starts incrementing, you'll hear the motor stop. At this point it is being held in a fixed position and taking data for about seven seconds. After this holding period you'll hear the motor quickly retract.

The red PRESS SCAN BUTTON will again appear. At this point, move the wire sample to a new location by pressing on the trigger and repositioning the wire. Then, press the SCAN button on the box again, and you'll be taking your second test. Continue on in this manner until you've done 10 tests. The screen will show the results of the test after each test so you'll know when the 10 tests are complete.

WHEN THE 10 TESTS ARE COMPLETE, click on "Step 4 End Test Session". This will save the data in a file and close out that test session.

You're now ready to proceed to the next wire. If you were testing wire #1, then you'll select wire #2. EACH TIME YOU START A NEW WIRE, you have to change the information in the "Enter Notes & Description" area. If you're testing the same aging level and wire, then all you have to do is edit the information that is already there. I.e. if the test description says "PVC A0 #1 DWP and you're ready to test wire 2, all you have to do is change the #1 to #2.

A test will take about 1 minute. When it is complete, the Indenter modulus value will be shown on the screen and the unit will be automatically reset for the next test.

Move the cable being tested to a new test point. Plan your test locations so that after 10 tests you've tested locations all along the length of the cable. In addition to moving the cable along its length, you should rotate the cable from test to test.

When 10 tests are complete, you've finished the testing on that wire. Click on Step 4 to tell the software that you're done with the testing on that wire.

PUT THE WIRE BACK IN THE BAG IT CAME FROM and put the bag in the TESTED box.

Take the next bag and test the wire in that bag starting with instruction X above.

COMPLETING AN AGING LEVEL:

When you've completed the FIVE wires in a wire aging level, you need to select a new "Step 1 Select Pre-Config Test". Thus, if you were testing PVC A0 and are now ready to test PVC A2, you need to select this from the Step 1 window.

COMPLETING A WIRE TYPE:

When you've completed all the aging levels for a wire type, then you need to click on RETURN TO MAIN MENU at the bottom of the testing screen and start over again by clicking on RUN TEST and selecting for the Project name the name of the wire you're now testing.

SOME GENERAL TEST NOTES:

Some of the wires have information printed on them. If possible, avoid testing in these areas.
Make sure the wire is sitting firmly in the V notch of the clamp. You can tell this by gently pulling on the wire to see if it appears to be clamped firmly.

SOME PROBLEMS YOU MAY INCUR:

You may encounter a message that says something about a Max Deformation error. (This will happen about once per test on the Polyimide wire types). If this happens, just click on OK and the program will proceed with displaying the test results. HOWEVER, the program won't automatically proceed – you'll have to click on the button Step 2 Start a Test to proceed.

APPENDIX C—BOEING ELONGATION-AT-BREAK TEST DATA

Test 02-033 Thermal Aging Wire Study
Insulation Elongation and Tensile Strength BMS 13-48T10C01G20

Specimen Number	W Weight (grams)	D Density (g/cm^3)	L Length (cm)	C Cross-sectional area (in^2)	F Breaking force of the specimen (lbf)	L_2 Distance between bench-marks at rupture (in)	Tensile strength (lbs/in^2)	Elongation at rupture by Instron (%)	Elongation per BSS 7324 by scale (%)
1 Control	0.30	1.6989	23.32	0.0012	8.532	8.933	7269.34	197.77	82.33
2 Control	0.30	1.7236	23.22	0.0012	5.552	8.699	4778.44	189.97	82.67
3 Control	0.30	1.7477	23.11	0.0012	7.926	8.432	6885.72	181.07	70.67
4 Control	0.30	1.7327	23.52	0.0011	8.196	8.954	7183.02	198.47	83.67
5 Control	0.26	1.7316	20.53	0.0011	7.904	8.030	6973.19	167.67	65.67
6 Control	0.30	1.7194	23.29	0.0012	8.019	8.332	6906.20	177.73	67.67
7 Control	0.27	1.7662	20.68	0.0011	8.782	9.135	7662.84	204.50	89.00
8 Control	0.29	1.6896	23.06	0.0012	8.082	8.700	7005.95	190.00	75.67
9 Control	0.26	1.7323	20.17	0.0012	8.079	8.765	7003.35	192.17	74.67
10 Control	0.30	1.6089	25.22	0.0011	8.375	9.235	7307.70	207.83	83.33
						Ave.	6897.58	190.72	77.53
1 3wks	0.25	1.6595	20.07	0.0012	6.700	6.366	5757.78	112.20	36.00
2 3wks	0.24	1.6116	19.84	0.0012	6.398	6.033	5498.25	101.10	58.67
3 3wks	0.24	1.6171	20.12	0.0011	6.750	6.028	5902.74	100.93	35.33
4 3wks	0.24	1.6344	19.94	0.0011	6.920	6.047	6062.06	101.57	35.00
5 3wks	0.24	1.6487	20.24	0.0011	6.554	5.942	5878.63	98.07	36.33
6 3wks	0.25	1.6965	20.07	0.0011	6.907	6.232	6068.04	107.73	38.67
7 3wks	0.24	1.6171	20.22	0.0011	6.499	5.946	5712.12	98.20	35.00
8 3wks	0.24	1.6173	20.07	0.0011	6.549	6.033	5713.15	101.10	34.33
9 3wks	0.25	1.6534	20.32	0.0012	6.686	6.033	5797.08	101.10	34.00
10 3wks	0.24	1.6011	20.37	0.0011	6.653	5.957	5833.30	98.57	34.67
						Ave.	5822.31	102.06	37.80
1 6wks	0.24	1.6783	19.86	0.0011	5.825	5.433	5220.04	81.10	29.33
2 6wks	0.22	1.5167	20.19	0.0011	5.928	5.333	5324.34	77.77	22.33
3 6wks	0.24	1.7077	19.39	0.0011	5.612	5.033	4995.41	67.77	24.00
4 6wks	0.23	1.5922	20.11	0.0011	5.860	5.433	5263.26	81.10	27.67
5 6wks	0.24	1.6141	20.07	0.0011	5.734	5.366	4992.32	78.87	28.00
6 6wks	0.23	1.6574	18.98	0.0011	5.939	6.366	5239.60	112.20	41.67
7 6wks	0.22	1.5326	19.76	0.0011	5.657	5.133	5024.23	71.10	22.67
8 6wks	0.22	1.5282	19.86	0.0011	5.682	5.466	5057.72	82.20	29.67
9 6wks	0.24	1.6751	19.81	0.0011	5.947	5.466	5305.47	82.20	27.33
10 6wks	0.23	1.6089	19.81	0.0011	5.664	5.666	5064.36	88.87	29.00
						Ave.	5148.67	82.32	28.17
1 9wks	0.23	1.5957	20.07	0.0011	5.133	4.433	4610.29	47.77	13.33
2 9wks	0.23	1.5609	20.20	0.0011	5.165	4.599	4566.87	53.30	13.33
3 9wks	0.23	1.5880	19.94	0.0011	4.916	4.366	4366.11	45.53	14.00
4 9wks	0.23	1.5977	19.86	0.0011	2.709	3.466	2411.36	15.53	1.33
5 9wks	0.23	1.5832	19.74	0.0011	5.206	4.899	4562.57	63.30	18.00
6 9wks	0.21	1.4787	19.51	0.0011	5.040	4.833	4466.27	61.10	17.33
7 9wks	0.23	1.5941	19.86	0.0011	5.156	4.699	4579.27	56.63	16.67
8 9wks	0.22	1.5113	20.04	0.0011	4.987	4.466	4429.17	48.87	13.67
9 9wks	0.22	1.5739	19.33	0.0011	5.098	4.966	4548.06	65.53	21.00
10 9wks	0.22	1.5365	19.89	0.0011	5.305	4.766	4754.05	58.87	17.33
						Ave.	4329.40	51.64	14.60
1 12wks	0.24	1.5476	21.59	0.0011	4.248	3.799	3815.42	26.63	3.67
2 12wks	0.21	1.5164	19.15	0.0011	4.692	4.299	4185.85	43.30	11.33
3 12wks	0.24	1.5441	21.59	0.0011	4.673	4.333	4187.68	44.43	11.33
4 12wks	0.22	1.4109	21.51	0.0011	4.478	4.099	3986.00	36.63	7.33
5 12wks	0.23	1.4989	21.41	0.0011	4.835	4.366	4352.46	45.53	12.33
6 12wks	0.23	1.4665	21.59	0.0011	5.027	4.566	4464.70	52.20	12.00
7 12wks	0.24	1.5657	21.44	0.0011	4.636	4.129	4182.79	37.63	11.00
8 12wks	0.24	1.5339	21.46	0.0011	4.475	4.033	3960.30	34.43	8.00
9 12wks	0.24	1.5402	21.51	0.0011	4.564	4.166	4065.28	38.87	9.33
10 12wks	0.23	1.5004	21.34	0.0011	4.613	4.233	4142.31	41.10	11.33
						Ave.	4134.28	40.08	9.77

Test 02-033 Thermal Aging Wire Study
Insulation Elongation and Tensile Strength BMS 13-48T10C01G20

Specimen Number	W Weight (grams)	L Length (cm)	F Breaking force of the specimen (lbf)	L_2 Distance between bench-marks at rupture (in)	Distance between bench-marks measured by scale (in)
1 Control	0.30	23.32	8.532	8.933	5.47
2 Control	0.30	23.22	5.552	8.699	5.48
3 Control	0.30	23.11	7.926	8.432	5.12
4 Control	0.30	23.52	8.196	8.954	5.51
5 Control	0.26	20.53	7.904	8.030	4.97
6 Control	0.30	23.29	8.019	8.332	5.03
7 Control	0.27	20.68	8.782	9.135	5.67
8 Control	0.29	23.06	8.082	8.700	5.27
9 Control	0.26	20.17	8.079	8.765	5.24
10 Control	0.30	25.22	8.375	9.235	5.50
1 3wks	0.25	20.07	6.7	6.366	4.08
2 3wks	0.24	19.84	6.398	6.033	4.76
3 3wks	0.24	20.12	6.75	6.028	4.06
4 3wks	0.24	19.94	6.92	6.047	4.05
5 3wks	0.24	20.24	6.554	5.942	4.09
6 3wks	0.25	20.07	6.907	6.232	4.16
7 3wks	0.24	20.22	6.499	5.946	4.05
8 3wks	0.24	20.07	6.549	6.033	4.03
9 3wks	0.25	20.32	6.686	6.033	4.02
10 3wks	0.24	20.37	6.653	5.957	4.04
1 6wks	0.24	19.86	5.825	5.433	3.88
2 6wks	0.22	20.19	5.928	5.333	3.67
3 6wks	0.24	19.39	5.612	5.033	3.72
4 6wks	0.23	20.11	5.86	5.433	3.83
5 6wks	0.24	20.07	5.734	5.366	3.84
6 6wks	0.23	18.98	5.94	6.366	4.250
7 6wks	0.22	19.76	5.657	5.133	3.68
8 6wks	0.22	19.86	5.682	5.466	3.89
9 6wks	0.24	19.81	5.947	5.466	3.82
10 6wks	0.23	19.81	5.664	5.666	3.87
1 9wks	0.23	20.07	5.133	4.433	3.40
2 9wks	0.23	20.20	5.165	4.599	3.40
3 9wks	0.23	19.94	4.916	4.366	3.42
4 9wks	0.23	19.86	2.709	3.466	3.04
5 9wks	0.23	19.74	5.206	4.899	3.54
6 9wks	0.21	19.51	5.04	4.833	3.52
7 9wks	0.23	19.86	5.156	4.699	3.50
8 9wks	0.22	20.04	4.987	4.466	3.41
9 9wks	0.22	19.33	5.098	4.966	3.63
10 9wks	0.22	19.89	5.305	4.766	3.52
1 12wks	0.24	21.59	4.248	3.799	3.11
2 12wks	0.21	19.15	4.692	4.299	3.34
3 12wks	0.24	21.59	4.673	4.333	3.34
4 12wks	0.22	21.51	4.478	4.099	3.22
5 12wks	0.23	21.41	4.835	4.366	3.37
6 12wks	0.23	21.59	5.027	4.566	3.36
7 12wks	0.24	21.44	4.636	4.129	3.33
8 12wks	0.24	21.46	4.475	4.033	3.24
9 12wks	0.24	21.51	4.564	4.166	3.28
10 12wks	0.23	21.34	4.613	4.233	3.34

Test 02-033 Thermal Aging Wire Study
Insulation Elongation and Tensile Strength BMS 13-48T10C01G20

Specimen Number	Starting gauge length between bench marks (in)	L_2 Distance between bench-marks at rupture (in)	Distance between bench-marks measured by scale (in)	**Elongation at rupture by Instron (%)**	**Elongation per BSS 7324 by scale (%)**
1 Control	3.00	8.933	5.47	197.77	82.33
2 Control	3.00	8.699	5.48	189.97	82.67
3 Control	3.00	8.432	5.12	181.07	70.67
4 Control	3.00	8.954	5.51	198.47	83.67
5 Control	3.00	8.030	4.97	167.67	65.67
6 Control	3.00	8.332	5.03	177.73	67.67
7 Control	3.00	9.135	5.67	204.50	89.00
8 Control	3.00	8.700	5.27	190.00	75.67
9 Control	3.00	8.765	5.24	192.17	74.67
10 Control	3.00	9.235	5.50	207.83	83.33
1 3wks	3.00	6.366	4.08	112.20	36.00
2 3wks	3.00	6.033	4.76	101.10	58.67
3 3wks	3.00	6.028	4.06	100.93	35.33
4 3wks	3.00	6.047	4.05	101.57	35.00
5 3wks	3.00	5.942	4.09	98.07	36.33
6 3wks	3.00	6.232	4.16	107.73	38.67
7 3wks	3.00	5.946	4.05	98.20	35.00
8 3wks	3.00	6.033	4.03	101.10	34.33
9 3wks	3.00	6.033	4.02	101.10	34.00
10 3wks	3.00	5.957	4.04	98.57	34.67
1 6wks	3.00	5.433	3.88	81.10	29.33
2 6wks	3.00	5.333	3.67	77.77	22.33
3 6wks	3.00	5.033	3.72	67.77	24.00
4 6wks	3.00	5.433	3.83	81.10	27.67
5 6wks	3.00	5.366	3.84	78.87	28.00
6 6wks	3.00	6.366	4.250	112.20	41.67
7 6wks	3.00	5.133	3.68	71.10	22.67
8 6wks	3.00	5.466	3.89	82.20	29.67
9 6wks	3.00	5.466	3.82	82.20	27.33
10 6wks	3.00	5.666	3.87	88.87	29.00
1 9wks	3.00	4.433	3.40	47.77	13.33
2 9wks	3.00	4.599	3.40	53.30	13.33
3 9wks	3.00	4.366	3.42	45.53	14.00
4 9wks	3.00	3.466	3.04	15.53	1.33
5 9wks	3.00	4.899	3.54	63.30	18.00
6 9wks	3.00	4.833	3.52	61.10	17.33
7 9wks	3.00	4.699	3.50	56.63	16.67
8 9wks	3.00	4.466	3.41	48.87	13.67
9 9wks	3.00	4.966	3.63	65.53	21.00
10 9wks	3.00	4.766	3.52	58.87	17.33
1 12wks	3.00	3.799	3.11	26.63	3.67
2 12wks	3.00	4.299	3.34	43.30	11.33
3 12wks	3.00	4.333	3.34	44.43	11.33
4 12wks	3.00	4.099	3.22	36.63	7.33
5 12wks	3.00	4.366	3.37	45.53	12.33
6 12wks	3.00	4.566	3.36	52.20	12.00
7 12wks	3.00	4.129	3.33	37.63	11.00
8 12wks	3.00	4.033	3.24	34.43	8.00
9 12wks	3.00	4.166	3.28	38.87	9.33
10 12wks	3.00	4.233	3.34	41.10	11.33

Test 02-033 Thermal Aging Wire Study
Insulation Elongation and Tensile Strength BMS 13-48T10C01G20

Specimen Number	Outer Dia. of insulation (in)	Outer Dia. of insulation (cm)	Inner Dia. of insulation (cm)	*Insulation thickness (mil)	Insulation thickness (cm)	Area of insulation (cm^2)	L Length (cm)	Volume of insulation (cm^3)	W Weight (grams)	D Density (g/cm^3)
1 Control	0.0547	0.1389	0.0983	8.0	0.02032	0.0076	23.32	0.1766	0.30	1.6989
2 Control	0.0542	0.1377	0.0971	8.0	0.02032	0.0075	23.22	0.1741	0.30	1.7236
3 Control	0.0538	0.1367	0.0960	8.0	0.02032	0.0074	23.11	0.1717	0.30	1.7477
4 Control	0.0534	0.1356	0.0950	8.0	0.02032	0.0074	23.52	0.1731	0.30	1.7327
5 Control	0.0531	0.1349	0.0942	8.0	0.02032	0.0073	20.53	0.1501	0.26	1.7316
6 Control	0.0542	0.1377	0.0970	8.0	0.02032	0.0075	23.29	0.1745	0.30	1.7194
7 Control	0.0536	0.1361	0.0955	8.0	0.02032	0.0074	20.68	0.1529	0.27	1.7662
8 Control	0.0539	0.1369	0.0963	8.0	0.02032	0.0074	23.06	0.1716	0.29	1.6896
9 Control	0.0539	0.1369	0.0963	8.0	0.02032	0.0074	20.17	0.1501	0.26	1.7323
10 Control	0.0536	0.1361	0.0955	8.0	0.02032	0.0074	25.22	0.1865	0.30	1.6089
1 3wks	0.0543	0.1379	0.0973	8.0	0.02032	0.0075	20.07	0.1507	0.25	1.6595
2 3wks	0.0543	0.1379	0.0973	8.0	0.02032	0.0075	19.84	0.1489	0.24	1.6116
3 3wks	0.0535	0.1359	0.0953	8.0	0.02032	0.0074	20.12	0.1484	0.24	1.6171
4 3wks	0.0534	0.1357	0.0950	8.0	0.02032	0.0074	19.94	0.1468	0.24	1.6344
5 3wks	0.0524	0.1330	0.0924	8.0	0.02032	0.0072	20.24	0.1456	0.24	1.6487
6 3wks	0.0533	0.1354	0.0947	8.0	0.02032	0.0073	20.07	0.1474	0.25	1.6965
7 3wks	0.0533	0.1353	0.0947	8.0	0.02032	0.0073	20.22	0.1484	0.24	1.6171
8 3wks	0.0536	0.1362	0.0955	8.0	0.02032	0.0074	20.07	0.1484	0.24	1.6173
9 3wks	0.0539	0.1369	0.0962	8.0	0.02032	0.0074	20.32	0.1512	0.25	1.6534
10 3wks	0.0534	0.1356	0.0949	8.0	0.02032	0.0074	20.37	0.1499	0.24	1.6011
1 6wks	0.0524	0.1331	0.0925	8.0	0.02032	0.0072	19.86	0.1430	0.24	1.6783
2 6wks	0.0523	0.1328	0.0922	8.0	0.02032	0.0072	20.19	0.1450	0.22	1.5167
3 6wks	0.0527	0.1339	0.0932	8.0	0.02032	0.0072	19.39	0.1405	0.24	1.7077
4 6wks	0.0523	0.1328	0.0922	8.0	0.02032	0.0072	20.11	0.1445	0.23	1.5922
5 6wks	0.0537	0.1364	0.0958	8.0	0.02032	0.0074	20.07	0.1487	0.24	1.6141
6 6wks	0.0531	0.1349	0.0942	8.0	0.02032	0.0073	18.98	0.1388	0.23	1.6574
7 6wks	0.0528	0.1341	0.0935	8.0	0.02032	0.0073	19.76	0.1435	0.22	1.5326
8 6wks	0.0527	0.1339	0.0932	8.0	0.02032	0.0072	19.86	0.1440	0.22	1.5282
9 6wks	0.0526	0.1336	0.0930	8.0	0.02032	0.0072	19.81	0.1433	0.24	1.6751
10 6wks	0.0525	0.1334	0.0927	8.0	0.02032	0.0072	19.81	0.1430	0.23	1.6089
1 9wks	0.0523	0.1328	0.0922	8.0	0.02032	0.0072	20.07	0.1441	0.23	1.5957
2 9wks	0.0530	0.1346	0.0940	8.0	0.02032	0.0073	20.20	0.1474	0.23	1.5609
3 9wks	0.0528	0.1341	0.0935	8.0	0.02032	0.0073	19.94	0.1448	0.23	1.5880
4 9wks	0.0527	0.1339	0.0932	8.0	0.02032	0.0072	19.86	0.1440	0.23	1.5977
5 9wks	0.0534	0.1356	0.0950	8.0	0.02032	0.0074	19.74	0.1453	0.23	1.5832
6 9wks	0.0529	0.1344	0.0937	8.0	0.02032	0.0073	19.51	0.1420	0.21	1.4787
7 9wks	0.0528	0.1341	0.0935	8.0	0.02032	0.0073	19.86	0.1443	0.23	1.5941
8 9wks	0.0528	0.1341	0.0935	8.0	0.02032	0.0073	20.04	0.1456	0.22	1.5113
9 9wks	0.0526	0.1336	0.0930	8.0	0.02032	0.0072	19.33	0.1398	0.22	1.5739
10 9wks	0.0524	0.1331	0.0925	8.0	0.02032	0.0072	19.89	0.1432	0.22	1.5365
1 12wks	0.0523	0.1328	0.0922	8.0	0.02032	0.0072	21.59	0.1551	0.24	1.5476
2 12wks	0.0526	0.1336	0.0930	8.0	0.02032	0.0072	19.15	0.1385	0.21	1.5164
3 12wks	0.0524	0.1331	0.0925	8.0	0.02032	0.0072	21.59	0.1554	0.24	1.5441
4 12wks	0.0527	0.1339	0.0932	8.0	0.02032	0.0072	21.51	0.1559	0.22	1.4109
5 12wks	0.0522	0.1326	0.0919	8.0	0.02032	0.0072	21.41	0.1534	0.23	1.4989
6 12wks	0.0528	0.1341	0.0935	8.0	0.02032	0.0073	21.59	0.1568	0.23	1.4665
7 12wks	0.0521	0.1323	0.0917	8.0	0.02032	0.0072	21.44	0.1533	0.24	1.5657
8 12wks	0.0530	0.1345	0.0939	8.0	0.02032	0.0073	21.46	0.1565	0.24	1.5339
9 12wks	0.0527	0.1338	0.0931	8.0	0.02032	0.0072	21.51	0.1558	0.24	1.5402
10 12wks	0.0523	0.1329	0.0922	8.0	0.02032	0.0072	21.34	0.1533	0.23	1.5004

*Per BMS 13-48J 2.2 Table 2

Test 02-033 Thermal Aging Wire Study
Insulation Elongation and Tensile Strength M16878/1

Specimen Number	W Weight (grams)	D Density (g/cm^3)	L Length (cm)	C Cross-sectional area (in^2)	F Breaking force of the specimen (lbf)	L_2 Distance between bench-marks at rupture (in)	Tensile strength (lbs/in^2)	Elongation at rupture by Instron (%)	Elongation per BSS 7324 by scale (%)
1 Control	0.31	1.6358	23.14	0.0013	4.589	10.055	3615.66	235.17	111.33
2 Control	0.31	1.6250	23.11	0.0013	5.552	10.450	4340.03	248.33	121.00
3 Control	0.27	1.5321	21.44	0.0013	4.524	9.686	3550.39	222.87	104.33
4 Control	0.30	1.6903	21.59	0.0013	4.577	10.357	3591.98	245.23	116.00
5 Control	0.32	1.6975	23.11	0.0013	4.486	10.155	3548.56	238.50	108.00
6 Control	0.27	1.6059	20.57	0.0013	4.664	9.826	3682.04	227.53	101.67
7 Control	0.29	1.4960	23.26	0.0013	4.521	10.447	3499.71	248.23	106.67
8 Control	0.31	1.6598	22.81	0.0013	4.486	10.374	3534.51	245.80	121.00
9 Control	0.31	1.6357	22.92	0.0013	4.541	10.613	3542.76	253.77	122.33
10 Control	0.31	1.6330	22.91	0.0013	4.53	10.747	3527.27	258.23	88.67
						Ave.	3643.29	242.37	110.10
1 2wks	0.30	1.6779	22.10	0.0013	4.775	10.029	3807.45	234.30	114.67
2 2wks	0.29	1.6391	21.44	0.0013	4.735	9.993	3701.38	233.10	113.00
3 2wks	0.26	1.7096	18.80	0.0013	4.744	9.683	3782.73	222.77	105.67
4 2wks	0.29	1.6333	21.51	0.0013	4.681	10.130	3659.16	237.67	114.00
5 2wks	0.30	1.6924	22.00	0.0012	4.62	10.033	3698.68	234.43	110.00
6 2wks	0.29	1.6438	21.21	0.0013	4.736	9.966	3673.29	232.20	114.67
7 2wks	0.29	1.6600	21.21	0.0013	4.682	10.107	3667.15	236.90	112.33
8 2wks	0.29	1.7114	20.78	0.0013	4.734	9.982	3744.74	232.73	109.67
9 2wks	0.30	1.2364	29.69	0.0013	4.754	10.766	3753.10	258.87	109.00
10 2wks	0.29	1.6589	21.87	0.0012	4.825	10.333	3894.14	244.43	110.67
						Ave.	3738.18	236.74	111.37
1 4wks	0.26	1.7520	18.64	0.0012	4.879	9.629	3953.76	220.97	85.67
2 4wks	0.30	1.7073	21.72	0.0013	4.82	10.12	3845.72	237.33	94.33
3 4wks	0.29	1.6765	21.21	0.0013	4.725	10.266	3737.62	242.20	100.00
4 4wks	0.30	1.7493	21.08	0.0013	4.775	10.464	3786.96	248.80	84.67
5 4wks	0.30	1.7397	21.79	0.0012	4.018	6.544	3276.05	118.13	26.00
6 4wks	0.28	1.7313	20.52	0.0012	4.87	9.666	3987.07	222.20	91.33
7 4wks	0.21	1.7117	15.32	0.0012	4.88	10.044	3930.56	234.80	97.00
8 4wks									
9 4wks									
10 4wks									
						Ave.	3788.25	217.78	82.71
1 6wks	0.27	1.6564	20.07	0.0013	4.772	10.033	3789.86	234.43	104.67
2 6wks	0.23	1.6982	16.84	0.0012	4.895	10.008	3926.74	233.60	101.67
3 6wks	0.27	1.7273	19.63	0.0012	4.785	10.333	3877.59	244.43	108.00
4 6wks	0.27	1.6763	19.71	0.0013	4.678	10.299	3693.10	243.30	107.33
5 6wks	0.28	1.8307	19.33	0.0012	4.855	10.676	3958.50	255.87	110.67
6 6wks	0.27	1.6880	19.38	0.0013	4.76	10.599	3720.92	253.30	114.33
7 6wks									
8 6wks									
9 6wks									
10 6wks									
						Ave.	3827.78	244.16	107.78
1 8wks									
2 8wks	0.26	1.5939	20.45	0.0012	4.87	7.849	3938.45	161.63	66.67
3 8wks	0.30	1.8354	20.45	0.0012	4.911	8.011	3963.55	167.03	71.33
4 8wks	0.27	1.6684	20.29	0.0012	4.954	8.729	4006.38	190.97	79.00
5 8wks	0.27	1.6647	20.50	0.0012	4.914	7.544	4006.60	151.47	50.67
6 8wks	0.27	1.6630	20.27	0.0012	5.05	8.741	4067.48	191.37	87.67
7 8wks	0.26	1.6076	20.52	0.0012	4.916	7.637	4024.73	154.57	68.67
8 8wks	0.28	1.6740	20.75	0.0012	4.964	9.203	3973.28	206.77	93.00
9 8wks	0.27	1.6820	20.37	0.0012	5.126	8.581	4196.66	186.03	78.33
10 8wks									
						Ave.	4022.14	176.23	74.42

Note: Blank area indicates sample broke upon removal of wire.

Test 02-033 Thermal Aging Wire Study
Insulation Elongation and Tensile Strength M16878/1

Specimen Number	Starting gauge length between bench marks (in)	L_2 Distance between bench-marks at rupture (in)	Distance between bench-marks measured by scale (in)	**Elongation at rupture by Instron (%)**	**Elongation per BSS 7324 by scale (%)**
1 Control	3.00	10.055	6.34	235.17	111.33
2 Control	3.00	10.450	6.63	248.33	121.00
3 Control	3.00	9.686	6.13	222.87	104.33
4 Control	3.00	10.357	6.48	245.23	116.00
5 Control	3.00	10.155	6.24	238.50	108.00
6 Control	3.00	9.826	6.05	227.53	101.67
7 Control	3.00	10.447	6.20	248.23	106.67
8 Control	3.00	10.374	6.63	245.80	121.00
9 Control	3.00	10.613	6.67	253.77	122.33
10 Control	3.00	10.747	5.66	258.23	88.67
1 2wks	3.00	10.029	6.44	234.30	114.67
2 2wks	3.00	9.993	6.39	233.10	113.00
3 2wks	3.00	9.683	6.17	222.77	105.67
4 2wks	3.00	10.130	6.42	237.67	114.00
5 2wks	3.00	10.033	6.30	234.43	110.00
6 2wks	3.00	9.966	6.44	232.20	114.67
7 2wks	3.00	10.107	6.37	236.90	112.33
8 2wks	3.00	9.982	6.29	232.73	109.67
9 2wks	3.00	10.766	6.27	258.87	109.00
10 2wks	3.00	10.333	6.32	244.43	110.67
1 4wks	3.00	9.629	5.57	220.97	85.67
2 4wks	3.00	10.12	5.83	237.33	94.33
3 4wks	3.00	10.266	6.00	242.20	100.00
4 4wks	3.00	10.464	5.54	248.80	84.67
5 4wks	3.00	6.544	3.78	118.13	26.00
6 4wks	3.00	9.666	5.74	222.20	91.33
7 4wks	3.00	10.044	5.91	234.80	97.00
8 4wks					
9 4wks					
10 4wks					
1 6wks	3.00	10.033	6.14	234.43	104.67
2 6wks	3.00	10.008	6.05	233.60	101.67
3 6wks	3.00	10.333	6.24	244.43	108.00
4 6wks	3.00	10.299	6.22	243.30	107.33
5 6wks	3.00	10.676	6.32	255.87	110.67
6 6wks	3.00	10.599	6.43	253.30	114.33
7 6wks	3.00	4.699	3.50	56.63	16.67
8 6wks					
9 6wks					
10 6wks					
1 8wks					
2 8wks	3.00	7.849	5.00	161.63	66.67
3 8wks	3.00	8.011	5.14	167.03	71.33
4 8wks	3.00	8.729	5.37	190.97	79.00
5 8wks	3.00	7.544	4.52	151.47	50.67
6 8wks	3.00	8.741	5.63	191.37	87.67
7 8wks	3.00	7.637	5.06	154.57	68.67
8 8wks	3.00	9.203	5.79	206.77	93.00
9 8wks	3.00	8.581	5.35	186.03	78.33
10 8wks					

Test 02-033 Thermal Aging Wire Study
Insulation Elongation and Tensile Strength M16878/1

Specimen Number	W Weight (grams)	L Length (cm)	F Breaking force of the specimen (lbf)	L_2 Distance between bench-marks at rupture (in)	Distance between bench-marks measured by scale (in)
1 Control	0.31	23.14	4.589	10.055	6.34
2 Control	0.31	23.11	5.552	10.450	6.63
3 Control	0.27	21.44	4.524	9.686	6.13
4 Control	0.30	21.59	4.577	10.357	6.48
5 Control	0.32	23.11	4.486	10.155	6.24
6 Control	0.27	20.57	4.664	9.826	6.05
7 Control	0.29	23.26	4.521	10.447	6.20
8 Control	0.31	22.81	4.486	10.374	6.63
9 Control	0.31	22.92	4.541	10.613	6.67
10 Control	0.31	22.91	4.53	10.747	5.66
1 2wks	0.30	22.10	4.775	10.029	6.44
2 2wks	0.29	21.44	4.735	9.993	6.39
3 2wks	0.26	18.80	4.744	9.683	6.17
4 2wks	0.29	21.51	4.681	10.130	6.42
5 2wks	0.30	22.00	4.62	10.033	6.30
6 2wks	0.29	21.21	4.736	9.966	6.44
7 2wks	0.29	21.21	4.682	10.107	6.37
8 2wks	0.29	20.78	4.734	9.982	6.29
9 2wks	0.30	29.69	4.754	10.766	6.27
10 2wks	0.29	21.87	4.825	10.333	6.32
1 4wks	0.26	18.64	4.879	9.629	5.57
2 4wks	0.30	21.72	4.82	10.12	5.83
3 4wks	0.29	21.21	4.725	10.266	6.00
4 4wks	0.30	21.08	4.775	10.464	5.54
5 4wks	0.30	21.79	4.018	6.544	3.78
6 4wks	0.28	20.52	4.87	9.666	5.74
7 4wks	0.21	15.32	4.88	10.044	5.91
8 4wks					
9 4wks					
10 4wks					
1 6wks	0.27	20.07	4.772	10.033	6.14
2 6wks	0.23	16.84	4.895	10.008	6.05
3 6wks	0.27	19.63	4.785	10.333	6.24
4 6wks	0.27	19.71	4.678	10.299	6.22
5 6wks	0.28	19.33	4.855	10.676	6.32
6 6wks	0.27	19.38	4.76	10.599	6.43
7 6wks					
8 6wks					
9 6wks					
10 6wks					
1 8wks					
2 8wks	0.26	20.45	4.87	7.849	5.00
3 8wks	0.30	20.45	4.911	8.011	5.14
4 8wks	0.27	20.29	4.954	8.729	5.37
5 8wks	0.27	20.50	4.914	7.544	4.52
6 8wks	0.27	20.27	5.05	8.741	5.63
7 8wks	0.26	20.52	4.916	7.637	5.06
8 8wks	0.28	20.75	4.964	9.203	5.79
9 8wks	0.27	20.37	5.126	8.581	5.35
10 8wks					

Test 02-033 Thermal Aging Wire Study
Insulation Elongation and Tensile Strength   M16878/1

Specimen Number	Outer Dia. of insulation (in)	Outer Dia. of insulation (cm)	Inner Dia. of insulation (cm)	*Insulation thickness (mil)	Insulation thickness (cm)	Area of insulation (cm^2)	L Length (cm)	Volume of insulation (cm^3)	W Weight (grams)	D Density (g/cm^3)
1 Control	0.0585	0.1486	0.1080	8.0	0.02032	0.0082	23.14	0.1895	0.31	1.6358
2 Control	0.0589	0.1496	0.1090	8.0	0.02032	0.0083	23.11	0.1908	0.31	1.6250
3 Control	0.0587	0.1491	0.1085	8.0	0.02032	0.0082	21.44	0.1762	0.27	1.5321
4 Control	0.0587	0.1491	0.1085	8.0	0.02032	0.0082	21.59	0.1775	0.30	1.6903
5 Control	0.0583	0.1481	0.1074	8.0	0.02032	0.0082	23.11	0.1885	0.32	1.6975
6 Control	0.0584	0.1483	0.1077	8.0	0.02032	0.0082	20.57	0.1681	0.27	1.6059
7 Control	0.0594	0.1509	0.1102	8.0	0.02032	0.0083	23.26	0.1939	0.29	1.4960
8 Control	0.0585	0.1486	0.1080	8.0	0.02032	0.0082	22.81	0.1868	0.31	1.6598
9 Control	0.0590	0.1499	0.1092	8.0	0.02032	0.0083	22.92	0.1895	0.31	1.6357
10 Control	0.0591	0.1501	0.1095	8.0	0.02032	0.0083	22.91	0.1898	0.31	1.6330
1 2wks	0.0579	0.1471	0.1064	8.0	0.02032	0.0081	22.10	0.1788	0.30	1.6779
2 2wks	0.0589	0.1496	0.1090	8.0	0.02032	0.0083	21.44	0.1769	0.29	1.6391
3 2wks	0.0579	0.1471	0.1064	8.0	0.02032	0.0081	18.80	0.1521	0.26	1.7096
4 2wks	0.0589	0.1496	0.1090	8.0	0.02032	0.0083	21.51	0.1776	0.29	1.6333
5 2wks	0.0577	0.1466	0.1059	8.0	0.02032	0.0081	22.00	0.1773	0.30	1.6924
6 2wks	0.0593	0.1506	0.1100	8.0	0.02032	0.0083	21.21	0.1764	0.29	1.6438
7 2wks	0.0588	0.1494	0.1087	8.0	0.02032	0.0082	21.21	0.1747	0.29	1.6600
8 2wks	0.0583	0.1481	0.1074	8.0	0.02032	0.0082	20.78	0.1694	0.29	1.7114
9 2wks	0.0584	0.1483	0.1077	8.0	0.02032	0.0082	29.69	0.2426	0.30	1.2364
10 2wks	0.0573	0.1455	0.1049	8.0	0.02032	0.0080	21.87	0.1748	0.29	1.6589
1 4wks	0.0571	0.1450	0.1044	8.0	0.02032	0.0080	18.64	0.1484	0.26	1.7520
2 4wks	0.0579	0.1471	0.1064	8.0	0.02032	0.0081	21.72	0.1757	0.30	1.7073
3 4wks	0.0583	0.1481	0.1074	8.0	0.02032	0.0082	21.21	0.1730	0.29	1.6765
4 4wks	0.0582	0.1478	0.1071	8.0	0.02032	0.0081	21.08	0.1715	0.30	1.7493
5 4wks	0.0568	0.1443	0.1036	8.0	0.02032	0.0079	21.79	0.1724	0.30	1.7397
6 4wks	0.0566	0.1438	0.1031	8.0	0.02032	0.0079	20.52	0.1617	0.28	1.7313
7 4wks	0.0574	0.1458	0.1052	8.0	0.02032	0.0080	15.32	0.1227	0.21	1.7117
8 4wks										
9 4wks										
10 4wks										
1 6wks	0.0581	0.1476	0.1069	8.0	0.02032	0.0081	20.07	0.1630	0.27	1.6564
2 6wks	0.0576	0.1463	0.1057	8.0	0.02032	0.0080	16.84	0.1354	0.23	1.6982
3 6wks	0.0571	0.1450	0.1044	8.0	0.02032	0.0080	19.63	0.1563	0.27	1.7273
4 6wks	0.0584	0.1483	0.1077	8.0	0.02032	0.0082	19.71	0.1611	0.27	1.6763
5 6wks	0.0568	0.1443	0.1036	8.0	0.02032	0.0079	19.33	0.1529	0.28	1.8307
6 6wks	0.0589	0.1496	0.1090	8.0	0.02032	0.0083	19.38	0.1599	0.27	1.6880
7 6wks										
8 6wks										
9 6wks										
10 6wks										
1 8wks										
2 8wks	0.0572	0.1453	0.1046	8.0	0.02032	0.0080	20.45	0.1631	0.26	1.5939
3 8wks	0.0573	0.1455	0.1049	8.0	0.02032	0.0080	20.45	0.1634	0.30	1.8354
4 8wks	0.0572	0.1453	0.1046	8.0	0.02032	0.0080	20.29	0.1618	0.27	1.6684
5 8wks	0.0568	0.1443	0.1036	8.0	0.02032	0.0079	20.50	0.1622	0.27	1.6647
6 8wks	0.0574	0.1458	0.1052	8.0	0.02032	0.0080	20.27	0.1624	0.27	1.6630
7 8wks	0.0566	0.1438	0.1031	8.0	0.02032	0.0079	20.52	0.1617	0.26	1.6076
8 8wks	0.0577	0.1466	0.1059	8.0	0.02032	0.0081	20.75	0.1673	0.28	1.6740
9 8wks	0.0566	0.1438	0.1031	8.0	0.02032	0.0079	20.37	0.1605	0.27	1.6820
10 8wks										

APPENDIX D—SUMMARY OF EXCLUDED DATA

12/09/2002		EXCLUDED TESTS BY MATERIAL, AGING LEVEL, TESTER					
		Total number of tests performed by each tester were 250 per wire type					
		for a total of 1500 tests (one modulus value and one relaxation value					
		obtained from each test					
	Aging	DWP	DWP	VICKI	VICKI	LISA	LISA
	Weeks	Modulus	Relax	Modulus	Relax	Modulus	Relax
PVC	0	0	0	0	10	0	1
	2	0	2	1	3	1	1
	4	1	0	0	5	0	0
	6	0	1	0	2	0	2
	8	0	1	0	2	2	0
Total PVC		1	4	1	22	3	4
PVC G-N	0	0	0	3	2	0	0
	2	0	1	0	1	0	0
	4	0	0	0	1	0	1
	6	0	1	0	2	0	0
	8	0	0	0	10	0	1
Total PVC G-N		0	2	3	16	0	2
XL-ETFE	0	0	1	0	4	0	0
	3	0	4	1	1	0	0
	6	0	3	0	0	1	0
	9	0	2	0	0	0	0
	12	0	1	0	2	0	0
Total XL-ETFE		0	11	1	7	1	0
COMPOSITE T	0	0	0	0	3	1	2
	3	0	1	0	4	2	1
	6	1	0	1	3	3	2
	9	1	2	0	0	1	0
	12	1	2	0	4	0	0
Total COMPOSITE TKT		3	5	1	14	7	5
POLYIMIDE IN	0	0	0	0	1	0	0
	3	0	0	2	1	1	3
	6	0	2	0	2	0	1
	9	0	4	0	0	1	0
	12	0	0	0	1	1	1
Total POLYIMIDE INST		0	6	2	5	3	5
POLYIMIDE P	0	1	1	0	0	0	1
	3	0	2	0	0	3	0
	6	0	2	0	1	1	0
	9	0	4	0	0	1	0
	12	0	3	1	0	1	0
Total POLYIMIDE POWER		1	12	1	1	6	1

		Dave	Dave	Vicki	Vicki	Lisa	Lisa
		Modulus	Relaxation	Modulus	Relaxation	Modulus	Relaxation
Total excluded by Tester		5	40	9	65	20	17
%		0.3%	2.7%	0.6%	4.3%	1.3%	1.1%

NOTE: The totals shown are out of 1500 individual tests

APPENDIX E—WIRE SPECIFICATIONS

INCH-POUND

MIL-DTL-16878/1C
11 August 2000
SUPERSEDING
MIL-W-16878/1B(NAVY)
11 September 1992

DETAIL SPECIFICATION SHEET

WIRE, ELECTRICAL, POLYVINYL CHLORIDE (PVC) INSULATED, 105 °C, 600 VOLTS (NOT FOR NAVY SHIPBOARD USE)

This specification is approved for use by all Departments and Agencies of the Department of Defense.

The requirements for acquiring the product described herein shall consist of this specification sheet and MIL-DTL-16878G.

REQUIREMENTS.

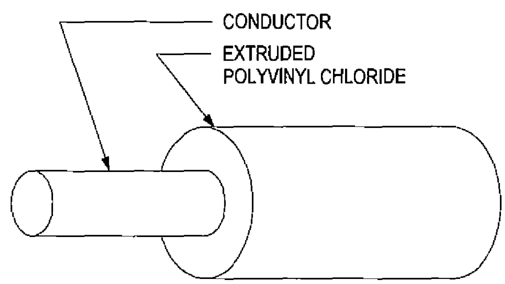


FIGURE 1. Wire configuration.

Note: Not for Navy shipboard use or use in aerospace applications.

TABLE I. Wire configuration and dimensions.

PIN [1/]	Wire size	Stranding	Conductor		Conductor diameter (nominal) (inch)	Finished wire diameter (inch)	
			Material [2/, 3/]	Coating		Min	Max
M16878/1BAA*	32	1 X 32	Copper	Tin	.008	.024	.030
M16878/1DAA*	32	1 X 32	H.S.C.A.	Silver	.008	.024	.030
M16878/1CAA*	32	1 X 32	C.C. steel	Tin	.008	.024	.030
M16878/1BAB*	32	7 X 40	Copper	Tin	.010	.026	.032
M16878/1DAB*	32	7 X 40	H.S.C.A.	Silver	.010	.026	.032
M16878/1BBA*	30	1 X 30	Copper	Tin	.010	.026	.032
M16878/1DBA*	30	1 X 30	H.S.C.A.	Silver	.010	.026	.032
M16878/1CBA*	30	1 X 30	C.C. steel	Tin	.010	.026	.032
M16878/1BBB*	30	7 X 38	Copper	Tin	.012	.028	.034
M16878/1DBB*	30	7 X 38	H.S.C.A.	Silver	.012	.028	.034
M16878/1BCA*	28	1 X 28	Copper	Tin	.013	.029	.035
M16878/1DCA*	28	1 X 28	H.S.C.A.	Silver	.013	.029	.035
M16878/1CCA*	28	1 X 28	C.C. steel	Tin	.013	.029	.035
M16878/1BCB*	28	7 X 36	Copper	Tin	.015	.031	.037
M16878/1DCB*	28	7 X 36	H.S.C.A.	Silver	.015	.031	.037
M16878/1BDA*	26	1 X 26	Copper	Tin	.016	.032	.038
M16878/1DDA*	26	1 X 26	H.S.C.A.	Silver	.016	.032	.038
M16878/1CDA*	26	1 X 26	C.C. steel	Tin	.016	.032	.038
M16878/1BDB*	26	7 X 34	Copper	Tin	.019	.035	.041
M16878/1DDB*	26	7 X 34	H.S.C.A.	Silver	.019	.035	.041
M16878/1BDE*	26	19 X 38	Copper	Tin	.021	.035	.041
M16878/1DDE*	26	19 X 38	H.S.C.A.	Silver	.021	.035	.041
M16878/1BEA*	24	1 X 24	Copper	Tin	.020	.036	.043
M16878/1DEA*	24	1 X 24	H.S.C.A.	Silver	.020	.036	.043
M16878/1CEA*	24	1 X 24	C.C. steel	Tin	.020	.036	.043
M16878/1BEB*	24	7 X 32	Copper	Tin	.024	.040	.047
M16878/1DEB*	24	7 X 32	H.S.C.A.	Silver	.024	.040	.047
M16878/1BEE*	24	19 X 36	Copper	Tin	.026	.040	.047
M16878/1DEE*	24	19 X 36	H.S.C.A.	Silver	.026	.040	.047
M16878/1BFA*	22	1 X 22	Copper	Tin	.025	.041	.048
M16878/1DFA*	22	1 X 22	H.S.C.A.	Silver	.025	.041	.048
M16878/1CFA*	22 [4/]	1 X 22	C.C. steel	Tin	.025	.041	.048
M16878/1BFB*	22	7 X 30	Copper	Tin	.030	.046	.053
M16878/1DFB*	22	7 X 30	H.S.C.A.	Silver	.030	.046	.053
M16878/1BFE*	22	19 X 34	Copper	Tin	.032	.046	.053
M16878/1DFE*	22	19 X 34	H.S.C.A.	Silver	.032	.046	.053

TABLE I. Wire configuration and dimensions - Continued.

PIN [1]	Wire size	Stranding	Conductor		Conductor diameter (nominal) (inch)	Finished wire diameter (inch)	
			Material [2, 3]	Coating		Min	Max
M16878/1BGA*	20	1 X 20	Copper	Tin	.032	.048	.055
M16878/1DGA*	20	1 X 20	H.S.C.A.	Silver	.032	.048	.055
M16878/1BGB*	20	7 X 28	Copper	Tin	.038	.054	.061
M16878/1DGB*	20	7 X 28	H.S.C.A.	Silver	.038	.054	.061
M16878/1BGE*	20	19 X 32	Copper	Tin	.041	.054	.061
M16878/1BHA*	18	1 X 18	Copper	Tin	.040	.056	.063
M16878/1BHB*	18	7 X 26	Copper	Tin	.049	.065	.072
M16878/1BHE*	18	19 X 30	Copper	Tin	.051	.065	.072
M16878/1BJA*	16	1 X 16	Copper	Tin	.051	.067	.075
M16878/1BJE*	16	19 X 29	Copper	Tin	.059	.075	.083
M16878/1BKA*	14	1 X 14	Copper	Tin	.064	.080	.088
M16878/1BKE*	14	19 X 27	Copper	Tin	.072	.088	.096

Notes:
1/ PIN stands for part or identifying number (see figure 2).
2/ H.S.C.A. stands for high-strength copper alloy.
3/ C.C. stands for copper-clad.
4/ Inactive for new design.

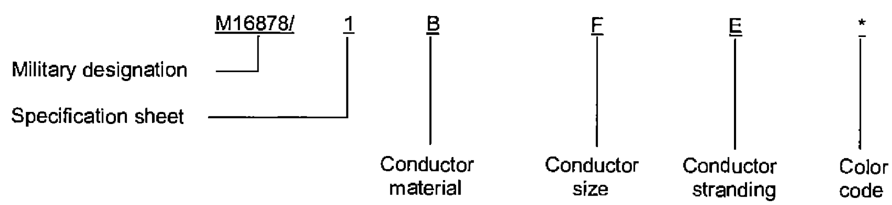


FIGURE 2. Example of PIN (see MIL-DTL-16878G).

Configuration and dimensions:	See figure 1 and table I
Operating voltage:	Up to 600 volts
Operating temperature:	Up to 105 °C
Insulation:	Extruded polyvinyl chloride
Spark test voltage:	3.4 kV
Impulse dielectric test voltage:	8.0 kV, or 5.7 kV using the 3.0 kHz spark test
Dielectric withstanding voltage:	2.0 kV

Insulation resistance: $IR = K \log_{10} D/d$

Where: IR = Minimum insulation resistance in megohms per 1000 feet at 20 °C

K = 2,000

D = Maximum average diameter of finished wire

d = Conductor diameter

Cold bend: Condition 4 hours at -54±1 °C (see table II)

TABLE II. Cold bend mandrel sizes.

Wire size	Cold bend mandrel diameter (inches, maximum)
32 through 26	1
24 through 14	2

Surface resistance: Not required

Heat resistance: Condition at 150 °C

Heat aging: 25 percent change (maximum) in 96 hours at 135 °C

Insulation tensile strength: 1800 pounds force per square inch (minimum)

Insulation elongation: 100 percent (minimum)

CHANGES FROM PREVIOUS ISSUE. Marginal notations are not used in this revision to identify changes with respect to the previous issues because of the extensiveness of the changes.

CONCLUDING MATERIAL

Custodians:
Navy - SH
Air Force - 11
DLA - CC

Review activity:
Navy - AS

Preparing activity:
DLA - CC

(Project 6145-2193-001)

MIL-W-5086/2C
23 November 1983
SUPERSEDING
MIL-W-5086/2B
2 December 1974
See also "Supersession Data" on Page 3

MILITARY SPECIFICATION SHEET

(C) WIRE, ELECTRICAL, POLYVINYL CHLORIDE INSULATED, PVC-GLASS-NYLON, TIN-COATED COPPER CONDUCTOR, 600-VOLT, 105°C

This specification is approved for use by all Departments and Agencies of the Department of Defense.

The complete requirements for acquiring the wire described herein shall consist of this document and the latest issue of Specification MIL-W-5086.

(C) FROM DATE OF ISSUE OF THIS REVISION, WIRE OF THIS SPECIFICATION SHEET SHALL NOT BE USED IN AEROSPACE APPLICATIONS. SEE "NON-USE" NOTE ON PAGE 3.

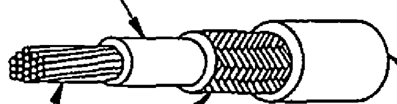


TABLE I. Construction details.

Part no. 1/	Wire size	Stranding (Number of strands X AWG gage of strands)	Diameter of stranded conductor (inches) (min)	Diameter of stranded conductor (inches) (max)	Finished wire: Resistance at 20°C (68°F) (ohms/1000 ft) (max)	Finished wire: Diameter (inches)	Finished wire: Weight (lbs/1000 ft) (max)
M5086/2-22-*	22	19 x 34	.029	.033	16.2	.075 ±.005	4.70
M5086/2-20-*	20	19 x 32	.037	.041	9.88	.085 ±.005	6.80
M5086/2-18-*	18	19 x 30	.046	.051	6.23	.095 ±.005	9.50
M5086/2-16-*	16	19 x 29	.052	.058	4.81	.105 ±.005	11.90
M5086/2-14-*	14	19 x 27	.065	.073	3.06	.125 ±.007	18.30
M5086/2-12-*	12	37 x 28	.084	.090	2.02	.143 ±.007	26.0
M5086/2-10-*	10	37 x 26	.106	.114	1.26	.189 ±.007	44.0
M5086/2-8-*	8	133 x 29	.158	.173	.701	.240 ±.007	70.0
M5086/2-6-*	6	133 x 27	.198	.217	.445	.293 ±.007	110.0
M5086/2-4-*	4	133 x 25	.250	.274	.280	.355 ±.010	165.0
M5086/2-2-*	2	665 x 30	.320	.340	.183	.425 ±.010	250.0
M5086/2-1-*	1	817 x 30	.360	.380	.149	.470 ±.010	305.0
M5086/2-01-*	0	1045 x 30	(C) .395	.425	.116	.525 ±.015	400.0
M5086/2-02-*	00	1330 x 30	(C) .440	.475	.091	.590 ±.015	500.0
M5086/2-03-*	000	1665 x 30	(C) .500	.540	.071	.650 ±.015	620.0
M5086/2-04-*	0000	2109 x 30	(C) .565	.605	.056	.720 ±.015	785.0

1/ Part no.: The asterisks in the part number column, Tables I through III, shall be replaced by color code designators in accordance with MIL-STD-681. Examples: Size 20, white - M5086/2-20-9; white with orange stripe - M5086/2-20-93.

(C) denotes changes

FSC 6145

(C) TABLE II. Bend test mandrels and test loads.

Part no.	Mandrel diameter (inches) (±3%)			Test load (lbs) (±3%)	
	Life cycle (oven and bend tests) 1/	Cold bend test	Wrap test	Life cycle (oven and bend tests) 1/	Cold bend test
M5086/2-22-*	4.5	3.0	0.45	.75	2.0
M5086/2-20-*	4.5	3.0	.51	.75	2.0
M5086/2-18-*	4.5	3.0	.57	1.0	2.0
M5086/2-16-*	6.5	3.0	.63	1.0	3.0
M5086/2-14-*	6.5	6.0	.75	1.0	3.0
M5086/2-12-*	6.5	6.0	.86	3.0	3.0
M5086/2-10-*	10.0	6.0	1.13	3.0	5.0
M5086/2-8-*	10.0	6.0	--	3.0	5.0
M5086/2-6-*	10.0	10.0	--	6.0	10.0
M5086/2-4-*	10.0	10.0	--	6.0	10.0
M5086/2-2-*	10.0	18.0	--	6.0	15.0
M5086/2-1-*	10.0	18.0	--	6.0	15.0
M5086/2-01-*	10.0	18.0	--	10.0	20.0
M5086/2-02-*	10.0	18.0	--	10.0	25.0
M5086/2-03-*	10.0	18.0	--	10.0	30.0
M5086/2-04-*	10.0	18.0	--	10.0	30.0

1/ Also for bend tests after immersion.

Wire ratings and additional requirements

Temperature rating: 105°C (221°F) max conductor temperature
Voltage rating: 600 volts (rms) at sea level
Blocking: 105° ±2°C (221° ±3.6°F)
Color: In accordance with MIL-STD-104, Class 1; white preferred
Color striping or banding durability:
 Sizes 22 through 10: 250 cycles (500 strokes) (min), 500 grams weight
 Sizes 8 through 0000: 50 cycles (100 strokes) (min), 250 grams weight
Flammability (Method I):
 30 sec (max) after-flame
 1.50 inches (max) flame travel, either direction on wire
 No flaming of tissue paper
Humidity resistance:
(C) Sizes 22 through 10: 40 megohms for 1000 ft, min insulation resistance after humidity exposure
 Sizes 8 through 0000: Not applicable
Identification durability:
 Sizes 22 through 10: 125 cycles (250 strokes) (min), 500 grams weight
 Sizes 8 through 0000: 50 cycles (100 strokes) (min), 250 grams weight
Impulse dielectric test:
 Primary insulation (when test is used in lieu of spark test): 6.0 kilovolts (peak), 100% test
 Finished wire: 8.0 kilovolts (peak), 100% test
Insulation resistance:
 Sizes 22 through 10: 40 megohms for 1000 ft (min)
 Sizes 8 through 0000: Not applicable
Life cycle: Oven temperature, 120° ±2°C (248° ±3.6°F)
Low temperature (cold bend): -55° ±2°C (-67° ±3.6°F)
Shrinkage: 0.125 inch max at 150° ±2°C (302° ±3.6°F)
Smoke: 110°C (230°F)
Spark test of primary insulation:
 Sizes 22 through 10: 3000 volts (rms), 60 Hz, 100% test
 Sizes 8 through 0000: 4000 volts (rms), 60 Hz, 100% test
Surface resistance:
 Sizes 22 through 10: 5 megohm-inches (min), initial and final readings
 Sizes 8 through 0000: Not applicable

Thermal shock: Oven temperature, 105° ±2°C (221° ±3.6°F)
Max change in measurement, 0.06 inch
Wet dielectric test: 2000 volts (rms)
Wrap test oven temperature:
Sizes 22 through 10: 95° ±2°C (203° ±3.6°F)
Sizes 8 through 0000: Not applicable
Wrap test specimens: In the selection of MIL-W-5086/2 wire specimens for the wrap test, each sample length from which a specimen is to be taken shall first be subjected to the dye inspection described under the wrap test procedure of MIL-W-5086, in order to detect glass fiber protrusions, if present, which permit dye penetration into the underlying braid. Specimens for the wrap test shall be cut only from those portions of each sample length which are free of such glass fiber protrusions.

(C) Metric conversion note: Data in this specification sheet may be converted to metric as follows:

Linear dimensions	25.40 x inches = millimeters (mm)
Weight (general)	.4536 x lbs = kilograms (kg)
Wire weight	1.488 x (lbs/1000 ft) = kg/km
Conductor resistance	3.281 x (ohms/1000 ft) = ohms/km
Insulation resistance	.3048 x (megohms for 1000 ft) = megohms for 1 km
Surface resistance	Metric documents may differ from MIL-STD-228 in spacing of the electrodes for this determination and in the method of expressing the test results. Where the electrode spacing is 25.0 millimeters in the metric document, the MIL-W-5086 megohm-inches resistance (defined as total megohms resistance times inches wire diameter) may be converted as follows:

25.0 x (megohm-inches diameter) = megohm-mm diameter
78.5 x (megohm-inches diameter) = megohm-mm circumference
3.14 x (megohm-inches diameter) = megohm-mm circumference per mm of electrode spacing

SUPERSESSION DATA: The wire of this specification sheet replaces and supersedes Type II wire of MIL-W-5086A (superseded 19 March 1968) and MS25190 (canceled 29 May 1969). Supersession by part number is in accordance with Table III.

TABLE III. Supersession by part number.

Size designation, MIL-W-5086A Type II	Part number, MS25190 Type II	Part number, MIL-W-5086/2
AN-22	MS25190-B-22	M5086/2-22-*
AN-20	MS25190-B-20	M5086/2-20-*
AN-18	MS25190-B-18	M5086/2-18-*
AN-16	MS25190-B-16	M5086/2-16-*
AN-14	MS25190-B-14	M5086/2-14-*
AN-12	MS25190-B-12	M5086/2-12-*
AN-10	MS25190-B-10	M5086/2-10-*
AN-8	MS25190-B-8	M5086/2-8-*
AN-6	MS25190-B-6	M5086/2-6-*
AN-4	MS25190-B-4	M5086/2-4-*
AN-2	MS25190-B-2	M5086/2-2-*
AN-1	MS25190-B-1	M5086/2-1-*
AN-0	MS25190-B-01	M5086/2-01-*
AN-00	MS25190-B-02	M5086/2-02-*
AN-000	MS25190-B-03	M5086/2-03-*
AN-0000	MS25190-B-04	M5086/2-04-*

(C) *NON-USE AND REPLACEMENT OF MIL-W-5086/2 WIRE IN AEROSPACE APPLICATIONS:* The exclusion of MIL-W-5086/2 wire from aerospace applications (page 1 of this document) is in consonance with the provisions of MIL-STD-454 and several military aerospace directives concerning polyvinyl chloride materials.

Replacement wires for the MIL-W-5086/2 items for aerospace applications should be selected from the lists of approved wires in the latest issue of MIL-W-5088, Wiring, Aerospace Vehicle, with due regard to the weight, dimensional, and functional requirements of the specific project or application.

INTERNATIONAL STANDARDIZATION: Certain provisions of Table 1 of this specification sheet are the subject of international standardization agreement (ASCC Air Std 12/5 and STANAG 3317). When amendment, revision, or cancellation of this specification sheet is proposed which will affect or violate the international agreement concerned, the preparing activity will take appropriate reconciliation action through international standardization channels including departmental standardization offices, if required.

Custodians:
Navy - AS
Army - CR
Air Force - 85

Review activities:
Navy - OS
Army - AR, ME, MI
Air Force - 99
DLA - IS
NSA

User activities:
Navy - EC, MC, SH
Army - AT, AV
Air Force - 11

Preparing activity:
Navy - AS
(Project No. 6145-0822-2)

☆ U.S. GOVERNMENT PRINTING OFFICE: 1983—705—040/A284

INCH - POUND

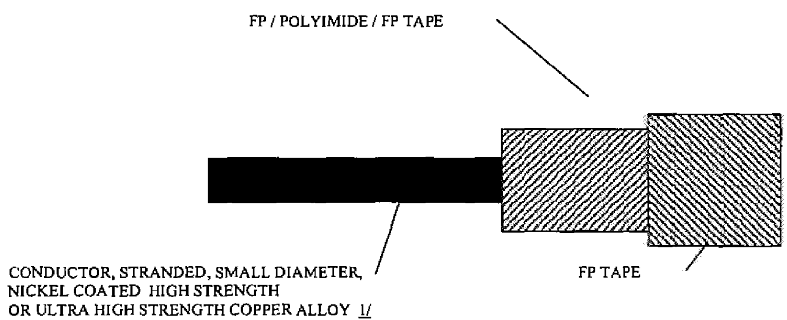
MIL-DTL-22759/90A
23 February 1998
SUPERSEDING
MIL-W-22759/90
9 September 1994

MILITARY SPECIFICATION SHEET

WIRE, ELECTRICAL, POLYTETRAFLUOROETHYLENE/POLYIMIDE
INSULATED, NORMAL WEIGHT, NICKEL COATED, HIGH STRENGTH OR ULTRA HIGH STRENGTH
COPPER ALLOY.260°C, 600 VOLTS.

This specification sheet has been approved by all departments and agencies within the Department of Defense; however it is not intended for use in Naval aircraft or Naval Air Systems applications.

The requirements for acquiring the product described herein shall consist of this specification sheet and the issue of the following specification listed in that issue of the Department of Defense Index of Specifications and Standards (DoDISS) specified in the solicitation: MIL-W-22759



FP - Fluorocarbon Polymer, modified Polytetrafluoroethylene (PTFE)

1/ Alloy Conductor: The size 26 AWG conductor shall be ultra-high strength copper alloy. The breaking strength shall be 21.5 lbs. (min.) and the conductor elongation shall be 6.0% (min). All other gauge sizes shall be high strength copper alloy in accordance with MIL-W-22759

FIGURE 1. General configuration.

AMSC N/A FSC 6145

DISTRIBUTION STATEMENT A. Approved for public release; distribution is unlimited

Table I. Construction details.

Part No. [1]	Wire Size	Conductor Stranding (number of strands x AWG gauge of strands)	Conductor Diameter (in.) MIN.	Conductor Diameter (in.) MAX.	Finished Wire Resistance at 20° C (68°F) (ohms/ 1000 ft max.)	Finished Wire Diameter (in.) Min.	Finished Wire Diameter (in.) Max.	Weight (lb./1000 Ft) (Max.)
M22759/90-26-*	26	19 x 38	0.0175	0.0204	58.4	0.033	0.037	1.55
M22759/90-24-*	24	19 x 36	0.0225	0.0254	30.1	0.038	0.042	2.15
M22759/90-22-*	22	19 x 34	0.0285	0.0314	18.6	0.043	0.047	3.00
M22759/90-20-*	20	19 x 32	0.0365	0.0404	11.4	0.051	0.055	4.55

[1] Part Number: The asterisks in the part number column of Table I shall be replaced by color code designators in accordance with MIL-STD-681. Examples: M22759/90-20-93 is a 20 AWG white with orange stripe.

Table II. Wire Insulation materials. [1]

Tape Code	Thickness (Nom)	Material
1	0.0020	0.0005 (FP) / 0.0010 (Polyimide) / 0.0005 (FP)
2	0.0020	FP (Unsintered)

[1] Physical properties of FP unsintered tapes shall be in accordance with MIL-W-22759 requirements.

TABLE III. Physical properties of FP/Polyimide/FP Tapes.

Tensile Strength	19,000 lb/in sq. (average minimum)
Tensile Modulus	350,000 lb/in sq. (average minimum)
Elongation	40 percent (average minimum)
Dielectric Strength	4,000 volts/mil (average minimum)
0.0005 FP Layer (bottom)	Distinguishable color (next to conductor) May be used at manufacturer's option

TABLE IV. Tape overlap requirements. [1]

Wire Size	Wrap 1 Tape Code	Wrap 1 Percent Overlap Min	Wrap 1 Percent Overlap Max	Wrap 2 Tape Code	Wrap 2 Percent Overlap Min	Wrap 2 Percent Overlap Max	Nominal Wall Thickness (mils)
26	1	50.5	54.0	2	50.5	54.0	7.4
24	1	50.5	54.0	2	50.5	54.0	7.4
22	1	50.5	54.0	2	50.5	54.0	7.4
20	1	50.5	54.0	2	50.5	54.0	7.4

[1] Wrap 1 is innermost tape which is in contact with the conductor.

TABLE V. Fluid table.

Test Fluid	Test temperature (°C (°F))	Immersion time (hrs.)
A. MIL-A-8243 Anti - icing and Deicing Defrosting Fluid, undiluted	48 - 50 (118 - 122)	20
B. MIL-A-8243 Anti - icing and Deicing Defrosting Fluid, diluted 60/40 (fluid/water) ratio	48 - 50 (118 - 122)	20
C. MIL-C-43616, Cleaning Compound, Aircraft Surface, Type I	48 - 50 (118 - 122)	20
D. ASTM D1153, Methyl Isobutyl Ketone (For use in Organic Coatings)	20 - 25 (68 - 77)	168
E. SAE AS 1241, Fire Resistant Hydraulic Fluid for Aircraft	48 - 50 (118 - 122)	20
F. MIL-L-7808, Lubricating Oil, Aircraft Turbine Engine, Synthetic Base	118 - 121 (244 - 250)	30
G. MIL-C-87937, Clean Compound, Aerospace Equipment, Type II or Type IV, undiluted	63 - 68 (145 - 154)	20
H. MIL-C-87937, Clean Compound, Aerospace Equipment, Type II or Type IV , diluted 25/75 (fluid/water) ratio	63 - 68 (145 - 154)	20
I. TT-S-735, Standard Test Fluids: Hydrocarbon, Type I	20 - 25 (68 - 77)	168
J. TT-S-735, Standard Test Fluids: Hydrocarbon, Type II	20 - 25 (68 - 77)	168
K. TT-S-735, Standard Test Fluids: Hydrocarbon, Type IV	20 - 25 (68 - 77)	168
L. Dielectric - coolant Fluid Synthetic Silicate Ester Base, Monsanto Coolanol 25 or approved equivalent.	20 - 25 (68 - 77)	168
M. MIL-G-3056, Gasoline, Automotive , Combat	20 - 25 (68 - 77)	168

RATINGS:

Temperature rating: 260° C (500°F) maximum continuous conductor temperature.
Voltage rating: 600 volts (rms.) at sea level

ADDITIONAL REQUIREMENTS:

Wet arc propagation resistance (Test required for initial qualification only): Test in accordance with MIL-STD-2223 Method 3006. Measure the damage of the bundle along the axis. The wire is acceptable if the following criteria are met:

1. A minimum of 67 wires pass the dielectric test.
2. Three wires or less fail the dielectric test in any one bundle.
3. Actual damage to the wire is not more than 3 inches in any test bundle.

Dry arc propagation resistance (Test required for initial qualification only): Test in accordance with MIL-STD-2223 Method 3007. Measure the damage of the bundle along the axis. The wire is acceptable if the following criteria are met:

1. A minimum of 67 wires pass the dielectric test.
2. Three wires or less fail the dielectric test in any one bundle.
3. Actual damage to the wire is not more than 3 inches in any test bundle.

Blocking: 260°C ± 2°C (500°F ± 3.6°F)

Color: In accordance with MIL-STD-104, class 1; except as noted below. White preferred. Conformity of color to the limits of MIL-STD-104 shall not be required after oven exposure.

Munsell color limits for UV laser markable wire

Color	Hue		Value		Chroma	
	From	To	From	To	From	To
Black	2.5RN	2.5RN	7	8.5	N/A	N/A
Blue	5PB	7.5B	7	8	4	6
Green	2.5G	7.5G	7	9	2	6
Red	10RP	5R	7	8	4	6
Yellow	5Y	10Y	8	9	4	6
Brown	2.5YR	7.5R	7	9	2	4
Orange	10R	2.5YR	6	7	8	10
Violet	2.5P	7.5R	7	8	4	8
Gray	Same as Black		Same as Black		Same as Black	

Color striping or banding durability: 125 cycles (250 strokes), 250 grams weight

Conductor strand adhesion: Not required

Continuous lengths: Schedule B

Dynamic cut- through (Test required for initial qualification only: Test in accordance with ASTM D 3032, Section 22. Blade shall be the standard cutting blade except the cutting edge radius shall be 0.005 ± 0.001 inch. Minimum average dynamic cut - through (lbs) shall be as follows:

Wire Size	23±5°C	150±5°C	200±5°C	260±5°C
26	10 lbs.	8 lbs.	6 lbs.	4 lbs.
20	15 lbs.	12 lbs.	10 lbs.	6 lbs.

Flammability: Test in accordance with MIL-STD-2223, Method 1006, Procedure A.

Requirements:

Duration of after - flame: 3 seconds (max)
Flame travel 3.0 inches (max)
No flaming of tissue

Forced Hydrolysis: (Test required for initial qualification only) 2000 hours at 70°C. Test 5 samples of AWG size 20 only in accordance with SAE AS4373 method 602. All 5 samples must pass the dielectric test as listed in method 602.

High frequency spark test: (When used in lieu of Impulse dielectric test) Test in accordance with MIL-STD-2223 Method 3008, 5.7 kilovolts (rms.) Test 100 percent of the wire.

Humidity resistance: After humidity exposure wire shall meet the requirements for initial insulation resistance.

Identification of product: Not required for size 26. Color code designator not required.

Identification durability: 125 cycles (250 strokes), 250 grams weight.

Immersion (Test required for initial qualification only): Test in accordance with MIL-STD-2223 Method 1001 including the additional fluids listed in Table V of this specification. Use mandrels and weights listed in Table VI for Bend testing. Dielectric test, 2500 volts (rms), 60 Hz. For turbine fuel immersion test of MIL-STD-2223, either JP 4 or MIL-T-83133 type JP-8 (NATO Type F-34) may be used.

Impulse dielectric test: 8.0 kilovolts (peak). Test 100 percent of the wire

Insulation resistance: 5000 megohms for 1000 feet (min.)

Insulation State of Sinter: (Test required for qualification) Evaluate FP layers with a Differential Scanning Calorimeter per ASTM D 4591.

	Energy to Melt (Joules/gram)
First Heat	Less than 25 J/g

Life cycle: 500 hours at 290°C ± 2°C (554°F ± 3.6°F). Dielectric test, 2500 volts (rms), 60 Hz. Use mandrels coated with polytetrafluoroethylene such that the diameter of the mandrels, after coating, still conform to the required test mandrels diameters of table VI. After oven exposure, layers shall not separate and or tapes shall not lift along the insulation or at the ends.

Low temperature (cold bend): Use mandrels and weights specified in Table VI. Chamber temperature , -65°C ± 2°C (-85°F ± 3.6°F). Dielectric test, 2500 volts (rms), 60 Hz.

Shrinkage: 0.091 inch (max.) at 290°C ± 2°C (554°F ± 3.6°F).

Smoke: 260°C ± 5°C (500°F ± 9°F); no visible smoke.

Solderability: Not required. This slash sheet is primarily intended for crimp terminations. For solderability applications use the silver coated copper version of this specification.

Strippability: (Group II quality conformance test). Test in accordance with ASTM D 3032 section 27. The length of the insulation slugs shall be 0.25 inches. There shall be no evidence of insulation left on the conductor when viewed with the naked eye. The strip forces (lbs.) shall be as follows:

Wire Size	Min. Force	Max. Force
26-20	0.25 lb.	6.0 lbs.

Tape Overlap: In accordance with MIL-STD-2223, method 6005.

Tensile Modulus: Test composite film in accordance with ASTM D 882, Method A.

Thermal index: 260°C (500°F) minimum for 10,000 hours (Test required for initial qualification only). Test size 20 only in accordance with ASTM D 3032, Section 14.

Thermal shock resistance: Oven temperature, 260°C ± 5°C (500°F ± 9°F), Maximum change in measurement , 0.091 inches. No cracking.

UV Laser Marking: (Test required for initial qualification only) FP materials shall be formulated in such a manner to achieve a 62 % minimum contrast level when marked by an Ultraviolet (UV) laser source operating at a delivered power not to exceed 1.5 Joules/cm^2. The contrast level is defined as

$$CL = \frac{\text{(Reflectance of the background insulation - Reflectance of the laser mark)}}{\text{Reflectance of the background insulation}} \times 100$$

Wrap (mandrel wrap): No cracking, no dielectric breakdown. Use mandrels specified in Table VI. Dielectric test, 2500 volts (rms), 60 Hz.

TABLE VI. Test mandrel and test load requirements.

Wire Size (AWG)	Test Mandrel Diameter [1/] (inches)			Test Load [1/] (lbs)	
	Cold Bend	Life Cycle/ Bend Test	Wrap	Cold Bend	Life Cycle/ Bend Test
26	1.00	0.375	0.125	3.00	0.50
24	1.00	0.500	0.125	3.00	0.75
22	1.00	0.500	0.125	4.00	1.00
20	1.00	0.500	0.125	4.00	1.50

[1/] Tolerance shall be ± 3 percent of the given values.

Qualification of wire:

For qualification, a source is required to submit data on quality conformance tests and any finished wire tests as required by the qualification authorization letter. All other testing will be performed by the qualifying activity at the source's expense.

Due to the extended time period over which the thermal index test is performed, a source may become qualified under this specification sheet while this test is still in progress.

Custodian:
Army - CR
Navy - AS
Air Force - 85
NASA - NA

Preparing Activity
Navy - AS

Project 6145-2142-11

Review Activities:
Army - AV, MI
Air Force - 11, 19, 70, 99
DLA - CC

SUPERSEDING
MIL-W-81381/12B
15 November 1972

MILITARY SPECIFICATION SHEET

WIRE, ELECTRIC, FLUOROCARBON/POLYIMIDE INSULATED, MEDIUM WEIGHT, NICKEL COATED COPPER CONDUCTOR, 600 VOLTS, 200°C, NOMINAL 8.4 OR 15.4 MIL WALL

This specification is approved for use by all Departments and Agencies of the Department of Defense.

The complete requirements for procuring the wire described herein shall consist of this document and the issue in effect of Specification MIL-W-81381.

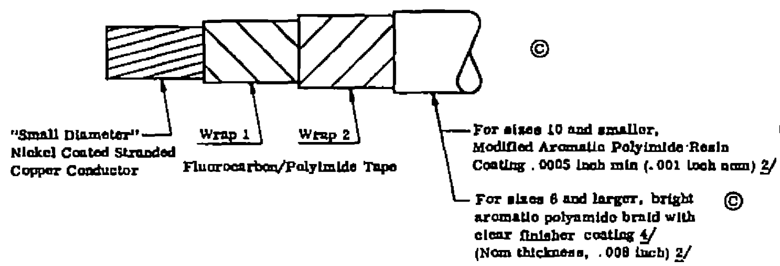


TABLE I. Construction details.

Part Number 1/	Wire Size	Conductor: Stranding (Number of Strands X AWG gage of strands)	Conductor: Diameter (inches) (min)	Conductor: Diameter (inches) (max)	Finished Wire: Resistance at 20°C (68°F) (ohms/1000 ft) (max)	Finished Wire: Diameter (inches) (min-max)	Finished Wire: Weight (lbs)/1000 ft) (nom) 2/	Finished Wire: Weight (lbs)/1000 ft) (max)	Insulation Tapes: Wrap 1 Tape Code 3/	Insulation Tapes: Wrap 1 Overlap(%) (min)	Insulation Tapes: Wrap 2 Tape Code 3/	Insulation Tapes: Wrap 2 Overlap(%) (min)
M81381/12-24-*	24	19 x 36	.023	.024	25.9	.040-.045	2.1	2.2	0/2/.5	50	.1/1/.1	50
M81381/12-22-*	22	19 x 34	.029	.031	16.0	.045-.050	3.0	3.2				
M81381/12-20-*	20	19 x 32	.037	.039	9.77	.053-.058	4.6	4.8				
M81381/12-18-*	18	19 x 30	.046	.049	6.10	.063-.068	6.8	7.2				
M81381/12-16-*	16	19 x 29	.052	.056	4.76	.068-.074	8.8	9.0				
© M81381/12-14-*	14	19 x 27	.065	.069	3.00	.081-.087	13.1	13.8				
© M81381/12-12-*	12	37 x 28	.084	.089	1.98	.100-.107	19.9	20.9				
© M81381/12-10-*	10	37 x 26	.106	.112	1.24	.122-.129	30.7	32.4				
© M81381/12-8-*	8	133 x 29	.158	.169	.694	.188-.206	56.7	61.8			.5/1/.5	50
© M81381/12-6-*	6	133 x 27	.198	.212	.436	.228-.251	90.4	95.1				
© M81381/12-4-*	4	133 x 25	.250	.268	.275	.280-.306	141	148				
© M81381/12-2-*	2	665 x 30	.320	.340	.177	.350-.378	224	235				

1/ Part Number: The asterisks in the part number column, Tables I and II, shall be replaced by color code designators in accordance with MIL-STD-681, except that opaque dark yellow as specified in MIL-W-81381 shall be designated by the letter "N" and unpigmented polyimide resin coating shall be designated by the letter "C". Examples: Size 20, opaque dark yellow - M81381/12-20-N; same with orange stripe - M81381/12-20-N3.

2/ Nominal values are for information only. Nominal values are not requirements.

3/ Tape Codes: 0/2/.5 2 mil polyimide film/0.5 mil FEP fluorocarbon resin
.1/1/.1 0.1 mil FEP fluorocarbon resin/1 mil polyimide film/0.1 mil FEP fluorocarbon resin
.5/1/.5 0.5 mil FEP fluorocarbon resin/1 mil polyimide film/0.5 mil FEP fluorocarbon resin

FEP = Fluorinated Ethylene Propylene

© 4/ Braid (Sizes 8 and larger): Bright aromatic polyamide yarn, 200 denier, 100 filaments, tightly formed, uniform in appearance, treated with a clear finisher coating. Finisher coating shall be compatible with the 200°C temperature rating and the performance requirements of the insulated wire.

© denotes changes.

FSC 6145

TABLE II. Performance details.

Part Number	Durability Test Load for: Color Markings (grams)	Durability Test Load for: Insulation Coatings (lbs)	Abrasion Resistance: Weight Support Bracket	Abrasion Resistance: Weight (lbs)	Abrasion Resistance: Tension Load (lbs)	Resistance (inches of tape) (min)	Bend Testing: Mandrel diameter (inches)(±3%): Life Cycle (Oven & bend tests) 2/	Bend Testing: Mandrel diameter (inches)(±3%): Cold Bend Test	Bend Testing: Mandrel diameter (inches)(±3%): Wrap Test	Bend Testing: Mandrel diameter (inches)(±3%): Wrinkle Test ©	Bend Testing: Test Load (lbs) (±3%): Life Cycle (Oven & bend tests) 2/	Bend Testing: Test Load (lbs) (±3%): Cold Bend Test
M81381/12-24-*	75	.75	A	1.0	1.0	12	.250	.250	.125	.156	.500	
M81381/12-22-*	100	1.00	A	1.0	1.0	14	.250	.250	.125	.188	.750	
M81381/12-20-*	100	1.00	A	1.0	1.0	16	.250	.250	.125	.250	.750	
M81381/12-18-*	150	1.00	A	1.0	1.0	18	.375	.375	.250	.312	1.00	
M81381/12-16-*	150	1.00	A	1.0	1.0	20	.375	.375	.250	.375	1.00	
M81381/12-14-*	150	1.00	B	1.0	2.0	24	.500	.375	.375	.500	2.00	
M81381/12-12-*	150	1.00	B	1.0	2.0	25	.750	.750	.375	.750	2.00	
M81381/12-10-*	150	1.00	B	1.0	2.0	26	.750	.750	.375	1.00	3.00	
M81381/12-8-*	150	1/	© C	4.25	2.0	18	2.00	2.00	1.00	1/	3.00	
M81381/12-6-*	150	1/	C	4.25	2.0	27	4.50	4.50	2.00	1/	3.00	
M81381/12-4-*	150	1/	C	4.25	2.0	27	6.00	6.00	3.00	1/	4.00	
M81381/12-2-*	150	1/	C	4.25	2.0	27	6.00	6.00	4.00	1/	6.00	

1/ Test not applicable

2/ Also for bend tests after immersion

WIRE RATINGS AND ADDITIONAL REQUIREMENTS

TEMPERATURE RATING: 200°C (392°F) max conductor temperature
VOLTAGE RATING: 600 volts (rms) at sea level
BLOCKING: Oven temperature, 200 ±2°C (392 ±3.6°F)
© BRAID FRAYING: The aromatic polyamide braid with finisher (wire sizes 8 and larger) shall be non-fraying and shall be firmly adherent to the underlying insulation. This examination shall be included in the MIL-W-81381 quality conformance inspection as a Group II characteristic, one specimen to be examined from each sample unit.
© COLOR: Sizes 24 through 10: As specified in contract or order in accordance with MIL-W-81381.
Sizes 8 through 2: The natural color of the finisher-treated aromatic polyamide braid (off-white to amber) is preferred (color designator "C"). Other colors, varying with the supplier, are available. The MIL-STD-104 color limits and the extended color limits of MIL-W-81381 are not applicable to these sizes.
FLAMMABILITY: 3 sec (max) after-flame
3.0 inches (max) flame travel
No flaming of tissue paper
HUMIDITY RESISTANCE: 5 megohms-1000 ft, min insulation resistance after humidity exposure
IDENTIFICATION OF PRODUCT: Required for sizes 22 and larger.
IDENTIFICATION, STRIPING, OR BANDING DURABILITY: 125 cycles (250 strokes); see Table II for test load.
IMPULSE DIELECTRIC TEST: 100% test; impulse voltage as specified in MIL-W-81381
INSULATION RESISTANCE: 2500 megohms-1000 ft (min)
LAMINATION SEALING: Oven temperature, 230 ±2°C (446 ±3.6°F)
LIFE CYCLE: Oven temperature, 230 ±2°C (446 ±3.6°F) for 500 hours
MINIMUM WALL THICKNESS: Sizes 24 through 10: 8.0 mils
Sizes 8 through 2: 15.0 mils
POLYIMIDE CURE TEST: Applicable to sizes 10 and smaller
PROPELLANT RESISTANCE: Test not required
© RESIN COATING DURABILITY: Sizes 24 through 10: 250 cycles (500 strokes); see Table II for test load.
Sizes 8 through 2: Test not applicable
SHRINKAGE: 0.031 inch (max) at 230 ±2°C (446 ±3.6°F)
SURFACE RESISTANCE: 5 megohms-inches (min), initial and final readings
THERMAL SHOCK: Oven temperature, 200 ±2°C (392 ±3.6°F) change in measurement, 0.031 inch (max)
WET DIELECTRIC TEST: 2500 volts (rms)
© WRINKLE TEST: Applicable to sizes 10 and smaller. No wrinkles shall be visible in the insulation at 3X magnification (3 diameters) after bending the wire one full turn around the mandrel specified in Table II. (The wire may be examined on the mandrel or after removal of the mandrel leaving the coil intact.) This test shall be included in the MIL-W-81381 quality conformance inspection as a Group II characteristic, one specimen to be tested from each sample unit.

INCH - POUND

MIL-DTL-22759/86
23 February 1998
SUPERSEDING
MIL-W-22759/86
9 September 1994

MILITARY SPECIFICATION SHEET

WIRE, ELECTRICAL, POLYTETRAFLUOROETHYLENE/POLYIMIDE
INSULATED, NORMAL WEIGHT, SILVER COATED, COPPER CONDUCTOR.
200°C, 600 VOLTS

This specification sheet has been approved by all departments and agencies within the Department of Defense; however it is not intended for use in Naval aircraft or Naval Air Systems applications.

The requirements for acquiring the product described herein shall consist of this specification sheet and the issue of the following specification listed in that issue of the Department of Defense Index of Specifications and Standards (DoDISS) specified in the solicitation: MIL-W-22759

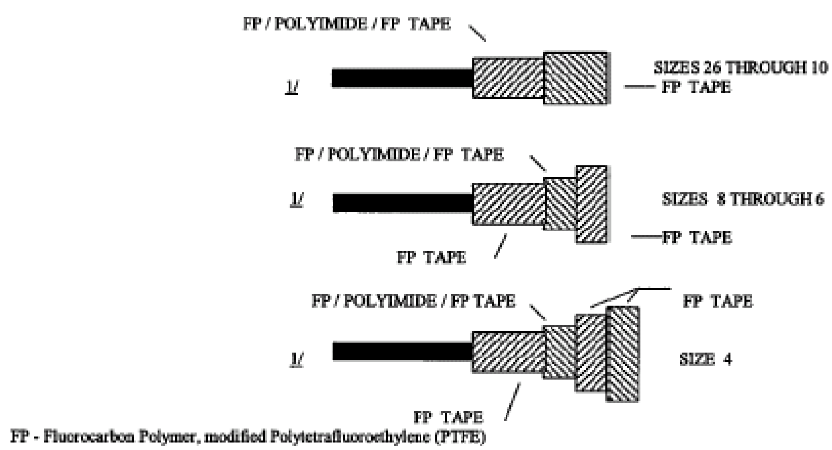


FIGURE 1. General configuration.

1/ Small diameter stranded silver coated copper conductor (sizes 26 to 4)

AMSC N/A FSC 614

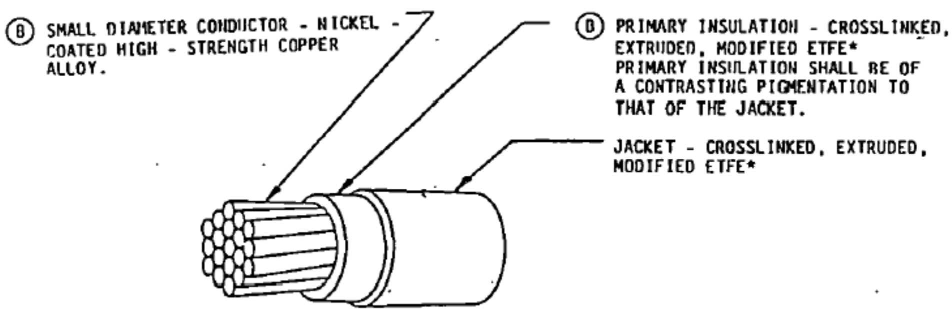
DISTRIBUTION STATEMENT A. Approved for public release; distribution is unlimited

MILITARY SPECIFICATION SHEET

Ⓑ WIRE, ELECTRICAL, FLUOROPOLYMER-INSULATED, CROSSLINKED MODIFIED ETFE, NORMAL WEIGHT, NICKEL-COATED HIGH-STRENGTH COPPER ALLOY, 200°C, 600 VOLT

This specification is approved for use by the Air Force Acquisition Logistics Division, Electronics Support Division (AFALD/PTES), Wright-Patterson AFB, Ohio 45433, Department of the Air Force, and is available for use by all departments and agencies of the Department of Defense.

The requirements for acquiring the wire described herein shall consist of this specification and the latest issue of MIL-W-22759.



* ETFE - Ethylene-tetrafluoroethylene copolymer

FIGURE 1. General configuration.

TABLE I. Construction details.

	Part no. 1/	Wire size	Stranding (number of strands x AWG gauge of strands)	Diameter of stranded conductor (inches) (min)	(max)	Finished wire Resistance at 20°C (68°F) (ohms/1000 ft) (max)	Diameter (inches)	Weight (lbs/1000 ft) (max)
Ⓑ	M22759/42-26-*	26	19 x 38	.018	.020	49.4	.040 ±.002	1.7
	M22759/42-24-*	24	19 x 36	.023	.025	30.1	.045 ±.002	2.3
	M22759/42-22-*	22	19 x 34	.029	.031	18.6	.050 ±.002	3.3
	M22759/42-20-*	20	19 x 32	.037	.039	11.4	.058 ±.002	4.8

1/ Part number: The asterisks in the part number column, tables I and II, shall be replaced by color code designators in accordance with MIL-STD-681. Examples: Size 20, white - M22759/42-20-9; white with orange stripe - M22759/42-20-93. Printing of color code designator on surface of wire insulation is not required.

Ⓑ denotes changes

DISTRIBUTION STATEMENT A. Approved for public release; distribution is unlimited.

TABLE II. Performance details.

Part no.	Bend testing: Mandrel diameter (inches) (±3%): Crosslinking proof, immersion and life cycle tests	Bend testing: Mandrel diameter (inches) (±3%): Cold bend test	Bend testing: Test load (lbs) (±3%): Crosslinking proof, immersion and life cycle tests	Bend testing: Test load (lbs) (±3%): Cold bend test
M22759/42-26-*	.375	1.00	.500	3.00
M22759/42-24-*	.500	1.00	.750	3.00
M22759/42-22-*	.500	1.00	1.00	3.00
M22759/42-20-*	.500	1.00	1.50	4.00

RATINGS:

Temperature rating: 200°C (392°F) maximum continuous conductor temperature.
Voltage rating: 600 volts (rms) at sea level.

ADDITIONAL REQUIREMENTS:

Acid resistance: No requirement.
Blocking: 230°C ±3°C (446°F ±5.4°F).
Color: In accordance with MIL-STD-104, class 1; white preferred. Conformity of color to the limits of MIL-STD-104 shall not be required after crosslinking proof test or life cycle oven exposure.
Color striping or banding durability: 125 cycles (250 strokes) (min), 500 grams weight.
Crosslinking proof test: 7 hours at 300°C ±3°C (572°F ±5.4°F). Quality conformance test, group II. Requirements and procedures as for life cycle except for time and temperature.
Dielectric test after immersion: 2,500 volts (rms), 60 Hz.
Flammability: Quality conformance test, group II. For requirements and procedures see below.
Humidity resistance: After humidity exposure, wire shall meet the requirements for initial insulation resistance.
Identification of product: Not required for size 24 and smaller. Color code designator not required.
Identification durability: 125 cycles (250 strokes) (min), 500 grams weight.
Immersion: For procedure see below.
Impulse dielectric test: 8.0 kilovolts (peak), 100 percent test.
Insulation resistance, initial: 5,000 megohms for 1,000 feet (min).
Insulation thickness:
  0.003 inch (min) for primary insulation.
  0.004 inch (min) for outer jacket.
  0.008 inch (min) for total insulation.
Life cycle: 500 hours at 230°C ±3°C (446°F ±5.4°F). Dielectric test, 2,500 volts (rms), 60 Hz. Procedure to use mandrels coated with polytetrafluoroethylene in the form of either enamel or wrapped tape, such that the diameter of the mandrels, after coating, still conform to the requirements of performance details, table II.
Low temperature (cold bend):
  Bend temperature, -65°C ±3°C (-85°F ±5.4°F).
  Dielectric test, 2,500 volts (rms), 60 Hz.
Physical properties of insulation: Pulled at 2 inches per minute. Primary insulation shall be separated from the outer jacket for determination of primary insulation tensile strength and elongation.
    Tensile strength, 5000 lbf/in^2 (min) for primary insulation, 500 lbf/in^2 (min) for total insulation (primary insulation and jacket).
    Elongation, 125 percent (min) for primary insulation, 75 percent (min) for total insulation (primary insulation and jacket).
Propellant resistance: No dielectric breakdown. For procedure see below.
Shrinkage: 0.125 inch (max) at 230°C ±3°C (446°F ±5.4°F).
Smoke: 250°C ±5°C (482°F ±9°F); no visible smoke.
(B) Solderability: Not applicable.
Spark test of primary insulation: 1,500 volts (rms), 60 Hz.
Surface resistance: 500 megohms - inches (min), initial and final readings.
Thermal shock resistance:
  Oven temperature, 200°C ±3°C (392°F ±5.4°F).
  Maximum change in measurement, 0.060 inch.

TABLE III. Immersion test fluids.

	Test fluid	Test temperature	Immersion time
a	MIL-L-23699, Lubricating Oil, Aircraft Turbine Engine, Synthetic Base	48°C to 50°C (118°F to 122°F)	20 hours
b	MIL-H-5606, Hydraulic Fluid, Petroleum Base, Aircraft, Missile, and Ordnance	48°C to 50°C (118°F to 122°F)	20 hours
c	TT-I-735, Isopropyl Alcohol	20°C to 25°C (68°F to 77°F)	168 hours
d	MIL-T-5624, Turbine Fuel, Aviation, Grade JP-4	20°C to 25°C (68°F to 77°F)	168 hours
e	MIL-A-8243, Anti-Icing and Deicing-Defrosting Fluid, undiluted	48°C to 50°C (118°F to 122°F)	20 hours
f	MIL-A-8243, Anti-Icing and Deicing-Defrosting Fluid, diluted 60/40 (fluid/water) ratio	48°C to 50°C (118°F to 122°F)	20 hours
g	MIL-C-43616, Cleaning Compound, Aircraft Surface	48°C to 50°C (118°F to 122°F)	20 hours
h	TT-M-268, Methyl Isobutyl Ketone (For Use in Organic Coatings)	20°C to 25°C (68°F to 77°F)	168 hours
i	SAE-AS-1241, Fire Resistant Hydraulic Fluid for Aircraft	48°C to 50°C (118°F to 122°F)	20 hours
j	MIL-L-7808, Lubricating Oil, Aircraft Turbine Engine, Synthetic Base	118°C to 121°C (244°F to 250°F)	30 minutes
k	MIL-C-25769, Cleaning Compound, Aircraft Surface, Alkaline Waterbase, undiluted	63°C to 68°C (145°F to 154°F)	20 hours
l	MIL-C-25769, Cleaning Compound, Aircraft Surface, Alkaline Waterbase, diluted 25/75 (fluid/water) ratio	63°C to 68°C (145°F to 154°F)	20 hours
m	TT-S-735, Standard Test Fluids; Hydrocarbon, Type I	20°C to 25°C (68°F to 77°F)	168 hours
n	TT-S-735, Standard Test Fluids; Hydrocarbon, Type II	20°C to 25°C (68°F to 77°F)	168 hours
o	TT-S-735, Standard Test Fluids; Hydrocarbon, Type III	20°C to 25°C (68°F to 77°F)	168 hours
p	TT-S-735, Standard Test Fluids; Hydrocarbon, Type VII	20°C to 25°C (68°F to 77°F)	168 hours
q	Dielectric-coolant fluid, synthetic silicate ester base, Monsanto Coolanol 25 or equivalent	20°C to 25°C (68°F to 77°F)	168 hours
r	MIL-T-81533, 1,1,1 Trichloroethane (Methyl Chloroform) Inhibited, Vapor Degreasing	20°C to 25°C (68°F to 77°F)	168 hours
s	Azeotrope of trichlorotrifluoroethane and methylene chloride, Dupont Freon TMC or equivalent	20°C to 25°C (68°F to 77°F)	168 hours
t	MIL-G-3056, Gasoline, Automotive, Combat	20°C to 25°C (68°F to 77°F)	168 hours

Wicking:
  Procedure II; weight increase, no requirement.
    Dye travel between layers of insulation, 2.25 inches (max) from end of specimen.
Wire length requirements: Schedule B.
Wrap test:
  Wrap back test.
  Oven temperature, 313°C ±3°C (595°F ±5.4°F).

Flammability requirements and procedure:

The flammability test of MIL-W-22759 shall be modified for the wire of this specification sheet as follows: The specified test burner shall be used without the wing top flame spreader and shall be adjusted to furnish a 3-inch conical flame with an inner cone approximately 1 inch in height and a temperature of 955°C ±30°C (1751°F ±54°F) at its hottest point. A sheet of facial tissue conforming to UU-T-450 shall be suspended taut and horizontal 9-1/2 inches below the marked point on the wire specimen in the test chamber and at least 1/2 inch above the floor of the chamber. The period of application of the hot flame tip to the marked point on the wire specimen shall be 30 seconds for all sizes of wire. Observations shall include time of burning after removal of the test flame, final distance of flame travel on the wire above the test mark, and presence or absence of flame in the facial tissue due to incendiary drip from the specimen. Requirements shall be:

Duration of after-flame	3 seconds (max)
Flame travel	3.0 inches (max)
No flaming of tissue	

Breaking of the wire specimen in size 24 or smaller shall not be considered as failure provided the requirements for duration of flame, final distance of flame travel, and absence of incendiary dripping are met.

One specimen shall be tested from each sample unit. The post-flame dielectric test of MIL-W-22759 is not required for wire of this specification sheet.

Immersion procedure:

A 24-inch specimen, for each test fluid in table III, shall have its diameter measured and shall then be immersed to within 6 inches of each end for the time and temperature specified. During immersion, the radius of bend of the wire shall be not less than 14 nor more than 35 times the specified maximum diameter of the wire under test. Upon removal from the test fluid, the specimen shall be wiped dry and then remain for 1 hour in free air at room temperature. The diameter shall be measured and compared to the initial diameter. The insulation shall be removed for a distance of 1/2 inch from each end of the specimen. The specimen shall then be subjected to the bend test and dielectric test specified in the procedure for life cycle testing.

Propellant resistance procedure: (Initial qualification test only)

Specimens of finished wire, 24 inches long, shall be immersed to within 1-1/2 inches of each end in the following propellants for the specified time at normal room temperature, using a separate specimen for each propellant.

Propellant	Immersion time
a. MIL-P-26536, Propellant, Hydrazine	30 minutes
b. MIL-P-26539, Propellant, Nitrogen Tetroxide	1 minute
c. MIL-P-27402, Propellant, Hydrazine - Uns-Dimethylhydrazine (50 percent N_2H_4 - 50 percent UDMH)	30 minutes

During immersion, the radius of bend of the wire shall be not less than 14 nor more than 35 times the specified maximum diameter of the wire under test. Upon removal from the liquids, the specimens shall remain for no more than 48 hours in free air at room temperature. The insulation shall be removed for a distance of 1 inch from each end of the specimens, and the specimens shall be subjected to the dielectric test specified for life cycle testing.

Qualifying activity: The activity responsible for the qualified products covered by this specification sheet is Naval Avionics Center, Code B/714, 6000 East 21st Street, Indianapolis, IN 46219-2189.

CONCLUDING MATERIAL

Custodians:
Army - AV
Navy - AS
Air Force - 85

Review activities:
Army - CR, MI
(8) Air Force - 11, 19, 70, 99
DLA - ES, IS

User activities:
Navy - EC, OS, SH

Preparing activity:
Air Force - 85

Agent:
DLA - ES

(Project 6145-1103-06)

APPENDIX F—WIRE INSULATION DETERIORATION ANALYSIS SYSTEM REPORT

WIRE INSULATION DETERIORATION ANALYSIS SYSTEM

WIDAS

Report for Pre-stressed and Control Boeing Spec. Wire Tests

AWG #10 MIL-DTL-22759/86A (PTFE-PI (Kapton)-PTFE composite)
&
AWG # 20 M81381 (PI (Kapton))

for

Analog Interfaces
P.O Box 3448
706 S. Union Av.
Alliance, OH 44601

performed under
Purchase Order Number: 22457 dated June 26, 2002

(P.O. amount represents sharing of actual costs)

Report Number: N2064-RPT06De2

by

Lectromechanical Design Company
45000 Underwood Lane, Suite-L
Dulles, VA 20166
Tel.: (703) 481-1233
Fax.: (703) 481-1238

Date: December 6, 2002

CONTENTS

INTRODUCTION

Lectromec's WIDAS process is a sampling test to determine the amount of deterioration that has occurred in wire insulation. The results of the WIDAS test indicate the amount of deterioration of physical and chemical properties and thus sensitivity to a proximate failure of the insulation. On an aircraft level, for instance, this test will provide a measure of the susceptibility to induced fracture of the aromatic polyimide insulation stemming from a maintenance action, vibration or inadvertent trauma.

OBJECTIVE

Instead of natural aging from the element, Analog Interfaces (& Boeing) wanted to study the effect of artificial aging under controlled conditions to quantify deterioration under predetermined environmental conditions. This would enable us to predict degradation. Boeing thermally aged AWG # 10 and AWG # 20 wire samples for 3,6,9 and 12 weeks and provided us with the samples to do our WIDAS tests. In addition, control samples of the unstressed wire were also provided. The objective was to quantify the aging state of the 5 groups (4 stressed and 1 control) of samples for each gage. The AWG # 10 wire is of Boeing spec. BMS 1360 which is a composite construction of PTFE (trade name Teflon) - followed by a layer of aromatic polyimide (PI) which is often duPont's Kapton (trade name) – followed by another layer of PTFE. In essence the BMS 1360 is mostly a Teflon-Kapton-Teflon (TKT) composite. The AWG # 20 wire is of Boeing spec. BMS 1351 and is only insulted with aromatic polyimide (PI) which is often duPont's Kapton (trade name).

METHODOLOGY

Three tests were identified to quantify the aging state:

1) Indenter tests (Analog Interfaces Inc.)
2) Viscosity Tests (Lectromec)
3) Hydrolysis Tests (Lectromec)

The Indenter will provide a measure of deterioration of physical properties (hardness).

The Viscosity test provides a measure of deterioration of chemical properties.

The Hydrolysis tests will provide a measure of the combined effect of the above.

Note that the Viscosity tests were not part of this contract and may be done later based on scheduling availability of equipment and personnel from other contractual commitments.

PROCEDURE

The indenter tests measure the force applied by a probe as it moves a small distance into the insulation (not to exceed 25 % of the insulation thickness). The modulus obtained can then be related to elongation at break. As the wire ages this modulus will change.

The Viscosity tests measure the weighted average molecular weight of the insulation which is a measure of the polymer chain length. As the insulation degrades, the chain length decreases. The procedure involves dissolving a limited amount of the insulation and measuring the inherent viscosity of the dissolved fluid. The molecular weight is calculated from the inherent viscosity.

The hydrolysis tests measure the life of insulation under predetermined strain when in contact with water at an elevated temperature. Each of the specimens is wrapped around a mandril whose diameter is eight to ten times the wire diameter, the length of wire wrap being one foot. Note that all the specimens (except "control") had a "V" or "U" shaped bend in them and the direction of wrap conformed to the orientation of the bend. The specimens are then submerged in distilled water and the temperature is raised to 95° C. Proof tests are periodically made to check insulation integrity. A failure is assessed when the leakage current from the proof tests exceeded 2 mA. The proof tests were conducted at 2500 VAC RMS, each applied test voltage period was 10 seconds. A specimen has failed when it develops a breach that is large enough to exceed 2 mA under the proof test. The proof test times were 0 hours, 5 hours, 17.5 hours, 30 hours, followed by a test every 12 hours. Note that the proof tests are applied only to check the integrity of the insulation. The samples are not aging under voltage stress.

TEST RESULTS

The tables on the following pages summarize the relevant information obtained from testing. Not that a few tests did not meet our QA standards and therefore were not reported. Even so, we still tested more than the required number of specimens called for by contract.

The failure rate curves plot the data tabulated in Figures 1 and 2. The rate curves show the progress of the test by plotting the number of failures versus elapsed time.

The degradation in property (resistance to hydrolysis and viscosity) is plotted against the time that Boeing pre-stressed samples in Figures 3 and 4. A line of best fit is also plotted to show the global degradation trend. The point of intersection of this line with the time axis is the projected end-of-life. The percent degradation can be obtained from the data tables.

BOEING SPEC. WIRE PRESTRESSED WIRE ANALYSIS STUDY BMS 13-60 T01C01G10 wire (AWG # 10) BMS 13-51 T14C01G20 wire (AWG # 20) WIDAS Test Reference Numbers: D02_12 Jar A and D02_13 Jars 1 to 8 and Jar A	STRESS ANALYSIS for BOEING by Analog Interfaces and LECTROMECHANICAL DESIGN CO. 45000-L Underwood Lane Sterling, VA 20166 phone 703 481 1233

WIRE DESCRIPTION / ANALYSIS	Wire Ident Reference	Hydrolysis: Average hr. Fail Time of Specimen	Hydrolysis: Mean hr. Fail Time of Group	Viscosity: Specimen Inherent Viscosity	Viscosity: Mean Viscosity of Group
AWG # 10 WIRE SPECIMENS	x101A1	Test did not meet Q.A.			
Control Wire	(x+1)102A2	372			
	(x+2)104A3	576			
Percent Shift in Mean of Failure Time (% Age):	(x+3)105A4	552			
0.00	(x+4)107A5	720	478.67		N/A
	(x+5)101A1	420			
Percent Shift in Mean of Viscosity (% Age):	(x+6)102A2	336			
N/A	(x+7)104A3	384			
	(x+8)105A4	672			
	(x+9)107A5	276			
AWG # 10 WIRE SPECIMENS	x102A2	Test did not meet Q.A.			
3 Weeks Oven Aging	(x+1)104A3	336			
	(x+2)105A4	216			
Percent Shift in Mean of Failure Time (% Age):	(x+3)107A5	168			
50.97	(x+4)101A1	168	234.67		N/A
	(x+5)102A2	264			
Percent Shift in Mean of Viscosity (% Age):	(x+6)104A3	252			
N/A	(x+7)105A4	240			
	(x+8)107A5	372			
	(x+9)101A1	96			
AWG # 10 WIRE SPECIMENS	x104A3	Test did not meet Q.A.			
6 Weeks Oven Aging	(x+1)105A4	216			
	(x+2)107A5	168			
Percent Shift in Mean of Failure Time (% Age):	(x+3)101A1	492			
41.50	(x+4)102A2	192	280.00		N/A
	(x+5)104A3	288			
Percent Shift in Mean of Viscosity (% Age):	(x+6)105A4	240			
N/A	(x+7)107A5	348			
	(x+8)101A1	204			
	(x+9)102A2	372			
AWG # 10 WIRE SPECIMENS	x105A4	Test did not meet Q.A.			
9 Weeks Oven Aging	(x+1)107A5	84			
	(x+2)101A1	168			
Percent Shift in Mean of Failure Time (% Age):	(x+3)102A2	408			
55.71	(x+4)104A3	228	212.00		N/A
	(x+5)105A4	120			
Percent Shift in Mean of Viscosity (% Age):	(x+6)107A5	216			
N/A	(x+7)101A1	192			
	(x+8)102A2	192			
	(x+9)104A3	300			
AWG # 10 WIRE SPECIMENS	x107A5	Test did not meet Q.A.			
12 Weeks Oven Aging	(x+1)101A1	336			
	(x+2)102A2	264			
Percent Shift in Mean of Failure Time (% Age):	(x+3)104A3	144			
48.47	(x+4)105A4	264	246.67		N/A
	(x+5)107A5	156			
Percent Shift in Mean of Viscosity (% Age):	(x+6)101A1	444			
N/A	(x+7)102A2	168			
	(x+8)104A3	288			
	(x+9)105A4	156			

BOEING SPEC. WIRE
PRESTRESSED WIRE ANALYSIS STUDY
BMS 13-60 T01C01G10 wire (AWG # 10)
BMS 13-51 T14C01G20 wire (AWG # 20)
WIDAS Test Reference Numbers:
D02_12 Jar A and D02_13 Jars 1 to 8 and Jar A

STRESS ANALYSIS for BOEING
by Analog Interfaces
and LECTROMECHANICAL DESIGN CO.
45000-L Underwood Lane
Sterling, VA 20166
phone 703 481 1233

WIRE DESCRIPTION / ANALYSIS	Wire Ident Reference	Hydrolysis		Viscosity	
		Average hr. Fail Time of Specimen	Mean hr. Fail Time of Group	Specimen Inherent Viscosity	Mean Viscosity of Group
AWG # 20 WIRE SPECIMENS	yA1	23.75			
Control Wire	yB2	36			
	yE3	36			
Percent Shift in Mean of Failure Time (% Age):	yF4	60			
0.00	(y+1)A1	48	34.70		N/A
	(y+1)B2	23.75			
Percent Shift in Mean of Viscosity (% Age):	(y+1)E3	23.75			
N/A	(y+1)F4	36			
	yA8	36			
	(y+1)A8	23.75			
AWG # 20 WIRE SPECIMENS	yA2	36			
3 Weeks Oven Aging	yB3	36			
	yE4	23.75			
Percent Shift in Mean of Failure Time (% Age):	yF5	36			
10.45	(y+1)A2	23.75	31.08		N/A
	(y+1)B3	36			
Percent Shift in Mean of Viscosity (% Age):	(y+1)E4	36			
N/A	(y+1)F5	11.25			
	yA6	36			
	(y+1)A7	36			
AWG # 20 WIRE SPECIMENS	yA3	36			
6 Weeks Oven Aging	yB4	36			
	yE5	23.75			
Percent Shift in Mean of Failure Time (% Age):	yF1	23.75			
10.45	(y+1)A3	36	31.08		N/A
	(y+1)B4	48			
Percent Shift in Mean of Viscosity (% Age):	(y+1)E5	36			
N/A	(y+1)F1	23.75			
	yB6	23.75			
	(y+1)B7	23.75			
AWG # 20 WIRE SPECIMENS	yA4	23.75			
9 Weeks Oven Aging	yB5	36			
	yE1	23.75			
Percent Shift in Mean of Failure Time (% Age):	yF2	23.75			
13.98	(y+1)A4	48	29.85		N/A
	(y+1)B5	23.75			
Percent Shift in Mean of Viscosity (% Age):	(y+1)E1	23.75			
N/A	(y+1)F2	36			
	yE6	36			
	(y+1)E7	23.75			
AWG # 20 WIRE SPECIMENS	yA5	23.75			
12 Weeks Oven Aging	yB1	36			
	yE2	23.75			
Percent Shift in Mean of Failure Time (% Age):	yF3	36			
24.57	(y+1)A5	23.75	26.18		N/A
	(y+1)B1	23.75			
Percent Shift in Mean of Viscosity (% Age):	(y+1)E2	23.75			
N/A	(y+1)F3	36			
	yF6	11.25			
	(y+1)F7	23.75			

AWG # 10 Failure Rate Curves (Wet Accelerated Aging)

Effect of Oven Aging for 5 different exposure time intervals

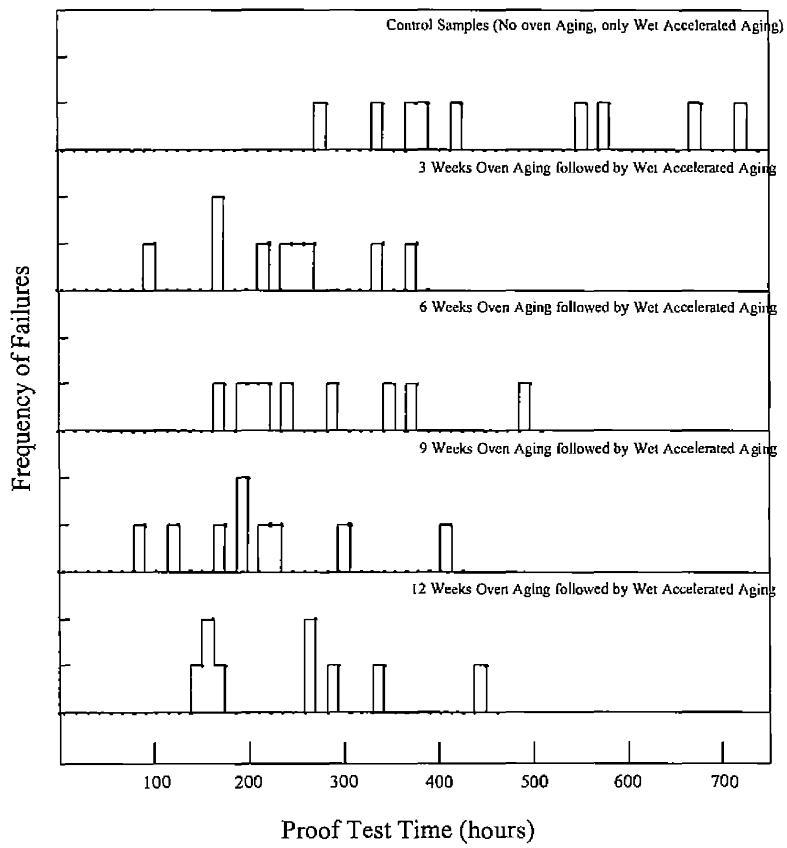


Figure 1

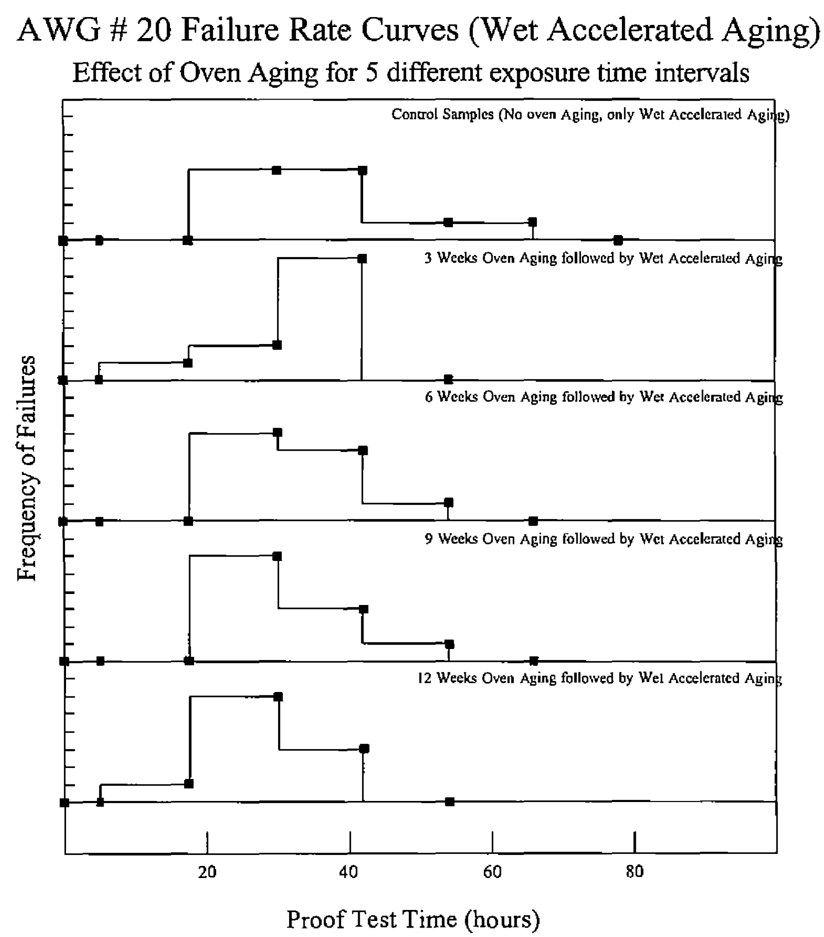

AWG # 20 Failure Rate Curves (Wet Accelerated Aging)
Effect of Oven Aging for 5 different exposure time intervals
Control Samples (No oven Aging, only Wet Accelerated Aging)
3 Weeks Oven Aging followed by Wet Accelerated Aging
6 Weeks Oven Aging followed by Wet Accelerated Aging
9 Weeks Oven Aging followed by Wet Accelerated Aging
12 Weeks Oven Aging followed by Wet Accelerated Aging
Frequency of Failures
20
40
60
80
Proof Test Time (hours)

Figure 2

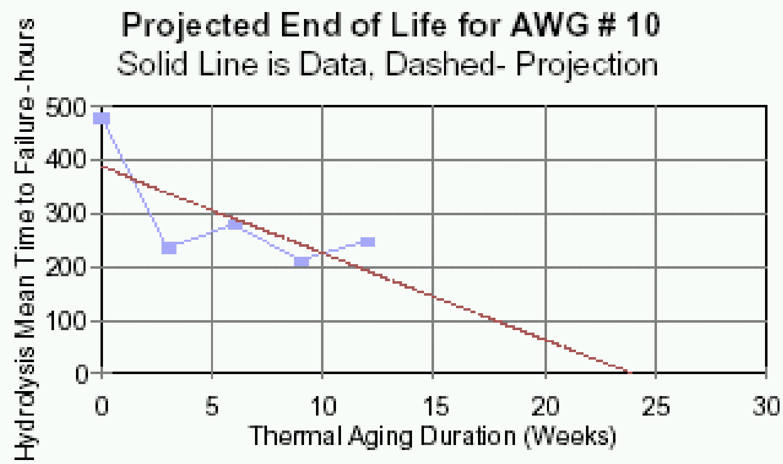


FIGURE 3 a

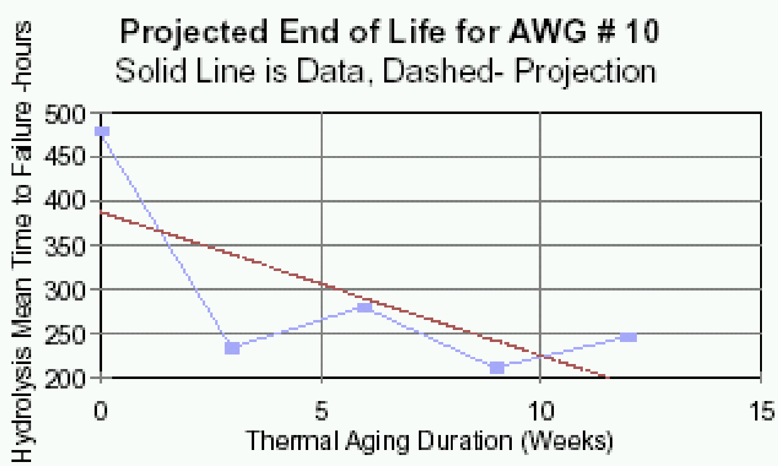


FIGURE 3 b (Enlarged 3 a)

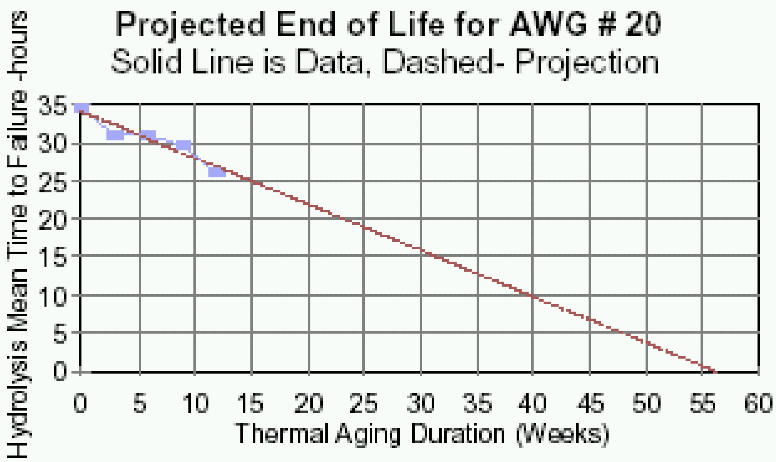


FIGURE 4 a

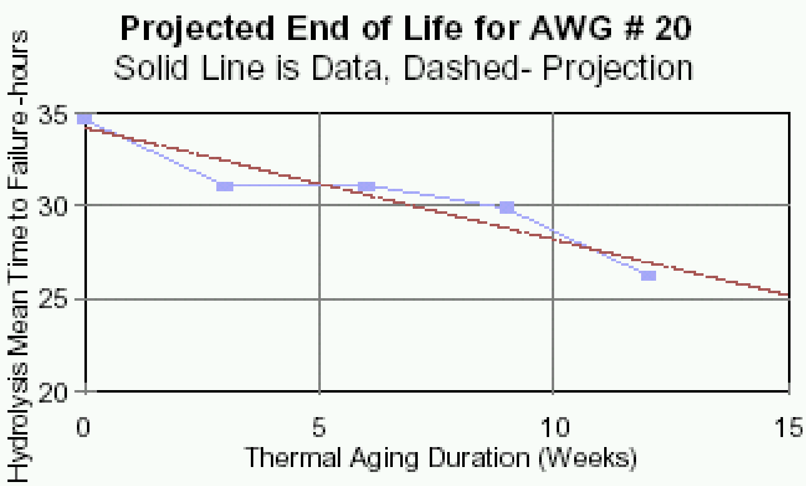


FIGURE 4 b (Enlarged 4 a)

COMMENTS, OBSERVATIONS AND DISCUSSION

The test times for the AWG # 20 wire are significantly lower than the AWG # 10 wire even though the strain on the AWG # 20 wire was slightly lower than the AWG # 10 wire. This is because the AWG # 10 wire has a different specification than the AWG # 20 wire. The AWG # 10 is a composite wire. We searched our database to for wire of similar construction and we found one that was similar. The wire had slightly different construction and the testing was done at slightly reduced strain, however the results obtained were of the same order of magnitude (between 170 and 300 hours). It is therefore not surprising that the life of some of the specimens was over 600 hours.

We also noticed that the aged wire had only a small length of the bend that the specimens were subjected to. Our standard length is one foot, which could explain why the aged specimen results were so inconsistent on average. There was no clear downward trend of life with oven aging. The line of best fit does suggest degradation but that is a global view point. The extrapolation to end of life is purely theoretical. To summarize,
The projected end of life for AWG # 10 wire is 24 weeks of oven aging.
The projected end of life for AWG # 20 wire is 56 weeks of oven aging.
Once again, we want to stress that these projections are only in theory.

We suggest that the Indenter test results be compared to the WIDAS results to see if a correlation can be found, even though the indenter specimens did not have an aging bend in them.

APPENDIX A

DEFINITIONS

Definition of Insulation Failure and Proximate Cause of Failure

At any given age condition of wire insulation there may be some level of applied stress which will cause the insulation to develop micro-cracks, porosity, or gross contact with ground which will allow leakage current. Lectromec defines a wire insulation as "failed" when such cracks or contact develop to the point that "significant" electrical leakage current can occur. Note this failure only occurs when the stress (proximate cause of failure) exceeds the ability of the aged insulation to carry that agreed upon specified stress. Also note that the insulation may have failed, by this definition, but not yet have evidenced any ultimate failure symptom. Bending, flexing, vibration, impact damage, and chafing/ abrasion/fretting are proximate causes of failure. Any of these types of "abuse" of wiring insulation can lead to the preceding condition defined as failure.

End-of-Life Definition

End-of-life of polyimide insulated wire depends upon two factors:

1. The rate of chemical deterioration of the polyimide wire from aging influences such as water, temperature, and mechanical elongation of the molecules (strain), and

2. The severity of mechanical breaking strains applied to the insulation which cause rupture of the insulation. Sometime after polyimide has failed by cracking, the insulation will allow current to flow from the conductor via various paths to ground or through other failed insulation of other conductors. The results are the intermittent or complete failure of operation of connected devices; or occasionally, arcing and flashover of wiring with consequential fire and interruption of more than one circuit.

APPENDIX G—RELATED REPORTS

INDENTER REPORTS

1. "Cable Indenter Aging Monitor," NP-5920, July 1988, Electric Power Research Institute, prepared by Franklin Research Center.

2. "Cable Indenter Aging Monitor," NP-7348, June 1991, Electric Power Research Institute, prepared by Franklin Research Center.

3. "Evaluation of Cable Polymer Aging Through Indenter Testing of In-Plant and Laboratory-Aged Specimens," TR-104075, January 1996, Electric Power Research Institute, prepared by Ogden Environmental and Energy Services Company.

4. "Aging, Condition Monitoring, and Loss-of-Coolant Accident (LOCA) Test of Class 1E Electrical Cables," NUREG/CR-5772, Volume 1, August 1992, Sandia National Laboratories for the US Nuclear Regulatory Commission.

5. "Evaluation of In-situ Cable Aging Through Indenter and Elongation Testing - Fermi Unit 2," December 1995, Project 272090000, Ogden Environmental and Energy Services Company.

6. "Indenter Testing Of Selected Cables From River Bend Station Drywell," Project 370720000, Ogden Environmental and Energy Services Company

7. "Investigation of Thermal Damage to LaSalle County Generating Station, Unit 1, Heater Bay Cables," Project No. 470730000, Ogden Environmental and Energy Services Company.

8. "Indenter Results From Site Visit To Yankee Rowe," Project No. 470910000, Ogden Environmental and Energy Services Company.

9. "Summary Report Indenter Testing of Martins Creek Unit 2 Cable on July 11, 1994," Project No. 471160000, Ogden Environmental and Energy Services Company.

10. "Indenter Polymer Aging Monitor Database Development for Use at the Exxon Baton Rouge Refinery," Report No. 7-7126-0000, May 1998, Ogden Environmental and Energy Services Company.

11. "Round-Robin Testing of Cable Materials (IAEA Co-ordinated Research Programme 2)," AEAT-3631 Issue 2, January 1999, AEA Technology.