Non Ceramic Insulator Workshop

Presented by R. Allen Bernstorf
The Dalles, Oregon
May 6, 1993

HUBBELL POWER SYSTEMS, INC. OHIO BRASS

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HI*LITE: THE HISTORY

The Ohio Brass Co. has been involved with non-ceramic insulating materials for almost a century. In 1895, we introduced the first organic insulation composed of shellac and asbestos and trade named S-Dirigo.

S-Dirigo was utilized in mining and transit insulators until it was replaced by a polystyrene-asbestos based compound in the 1950s. This material was trade named Dirigo.

Ohio Brass introduced a Bis-A epoxy pancake bushings in 1952. We introduced a cycloaliphatic epoxy distribution line post insulator in 1966. Although we built a pilot plant, we never commercially pursued that product.

The decision not to actively market the epoxy line post may have been influenced by development work taking place on a non-ceramic, composite insulator, trade named Hi*Lite.

The first trial units of the Hi*Lite insulator were sent into the field in 1971. These units were produced in a pilot plant housed within Ohio Brass's Research Facilities. Further development work was pursued, and the Hi*Lite product line was commercially introduced in 1976.

HI*LITE ANCESTRY

- EARLY 1900S - ORGANIC MINING/ STREET CAR INSULATORS
- 1950 - REPLACED SHELLAC WITH POLYSTYRENE
- 1952 - FIRST EPOXY PANCAKE BUSHINGS
- 1966 - EPOXY DISTRIBUTION CLASS LINE POSTS
- 1971 - FIRST HI*LITE FIELD TRIALS
- 1976 - HI*LITE PRODUCTION
- 1986 - HI*LITE II PRODUCTION
- 1990 - HI*LITE XL PRODUCTION

OH-1

FIGURE 1

The Ohio Brass Company's experience with organic insulating materials has grown from the mining and transit applications in the early 1900s, to the UHV transmission lines of today.

HI*LITE: THE DESIGN

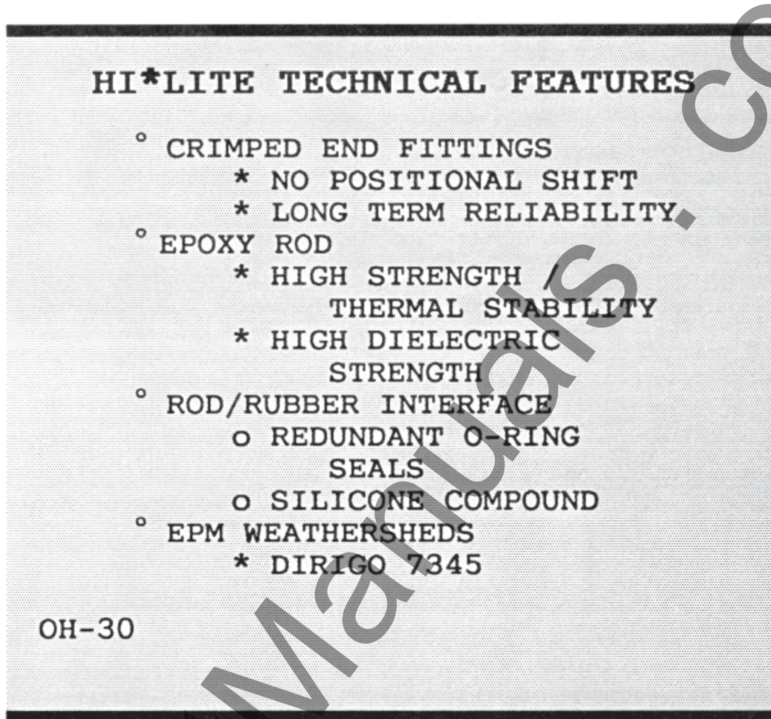

FIGURE 2

With the introduction of the Hi*Lite product line, a number of innovative design features were introduced to the marketplace. The Hi*Lite insulator utilized crimped end fittings, which maintained a high degree of positional integrity. To assure good thermal stability, high dielectric strength, and excellent mechanical strength, the end fittings were attached to an epoxy fiberglass rod. The rod/rubber interface was filled with a silicone compound, sometimes erroneously called a grease. This silicone compound is very highly filled and offers very high dielectric strength. The compound is held in place by a series of o-rings molded into the I.D. of the weathershed. This redundant sealing system offered a dynamic interface with the ability to follow loading strain excursions under virtually all conditions.

The real key to the design was the development of a suitable polymer compound. The original EPM compound, trade named Dirigo 7345, was developed by Ohio Brass to supply the characteristics which were desirable for long-term service exposures.

The Dirigo 7345 compound offered excellent resistance to breakdowns resulting from ultra-violet radiation and track resistance comparable to that offered by porcelain.

The Hi*Lite design provided corona control by a unique counterbored line end weathershed (see figure 3). This design isolated the air from the line end fitting, reducing the electrical stress.

As with most new products, there were some growing pains. The counterbored design of the line end weathershed eliminated the ability to apply a positive visual check for proper assembly. Improper insertion of the hardware could result in internal voids adjacent to the line end hardware. These voids could permit corona to form and result in cutting of the rubber or damage to the rod. Routine assembly gauging was implemented to correct this problem.

The counterbored end weathershed was also only partially effective in eliminating corona. High humidity or contaminated conditions increased the normal gradients and could result in corona. This could create a phenomenon known as corona cutting on the line end weathershed.

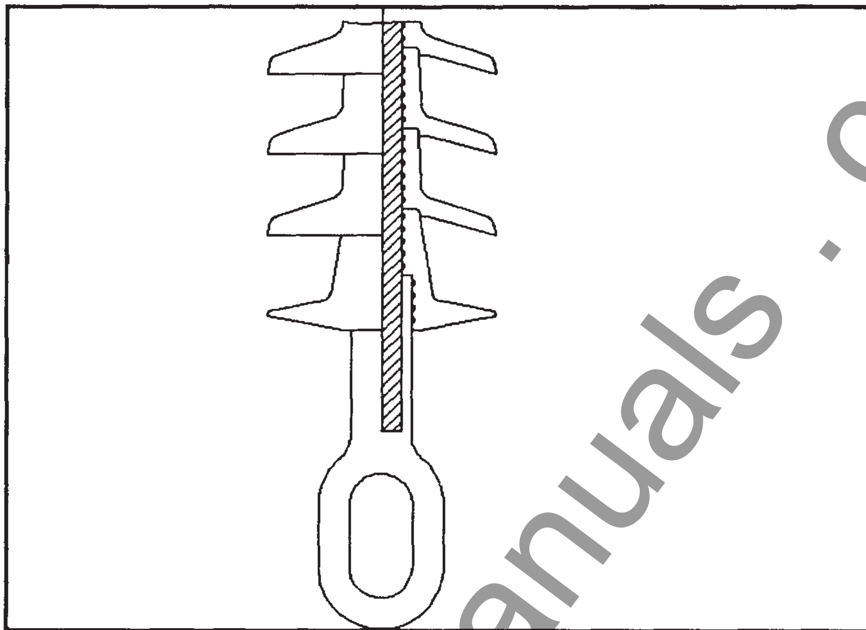

FIGURE 3 - HI*LITE SUSPENSION INSULATOR

As a result, all lines with operating voltages of 230 kV and above were retro-fitted with corona rings. Also, the level of anti-oxidant within the polymer compound was increased to improve the resistance of the compound to corona cutting.

Although these problems sound serious, the general experience with the Hi*Lite design was favorable. By the time the second generation Hi*Lite design was introduced in 1986, over 600,000 insulator years of experience had been accrued, and today, the experience for the first generation Hi*Lite design is over 2 million insulator years (see figure 4).

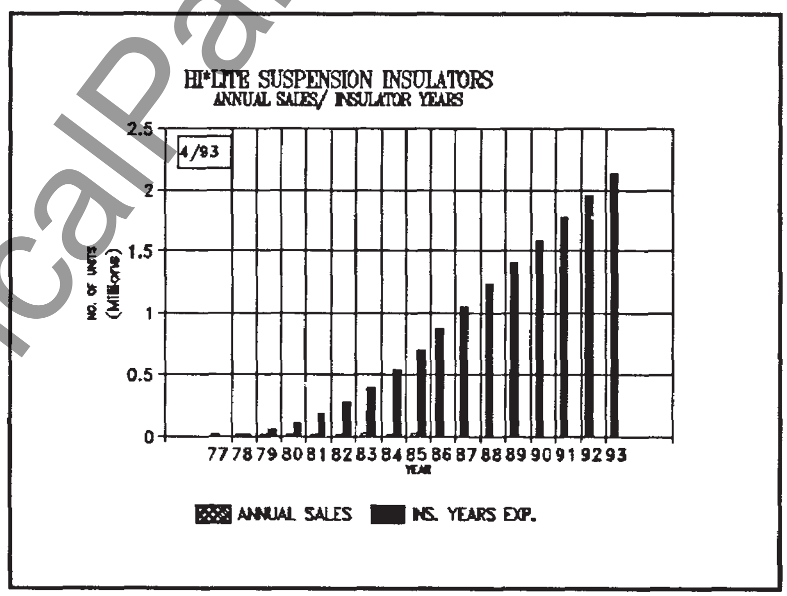

FIGURE 4

HI*LITE II: THE DESIGN

Reviewing the problems encountered with the first generation design lead to improvements which resulted in the introduction of the Hi*Lite II design. The strong features of the first generation design were maintained, like the crimped end fittings, the silicone compound in the rod/rubber interface and the o-ring seals. The use of epoxy rod was also maintained. A modified, high temperature vinyl ester rod was also approved.

HI*LITE II TECHNICAL FEATURES

FEATURES RETAINED

- ° CRIMPED END FITTINGS
- ° EPOXY ROD
  - * ADDED VINYL ESTER
- ° ROD/RUBBER INTERFACE

FEATURES ADDED

- ° STRESS DISTRIBUTION DISK
  - * GRADED FIELD
  - * ISOLATED CORONA
- ° OBALLOY 22 POLYMER
  - * EPM/SILICONE ALLOY
  - * ADDED HYDROPHOBICITY

OH-31

FIGURE 5

Then new features were added to address the weaker portions of the design. The original, counterbored line end weathershed was replaced with a Stress Distribution Disk (SDD). The SDD graded the electric field at the line end of the insulator. The SDD eliminated the blind counterbore problem which had forced us to gauge every insulator assembly.

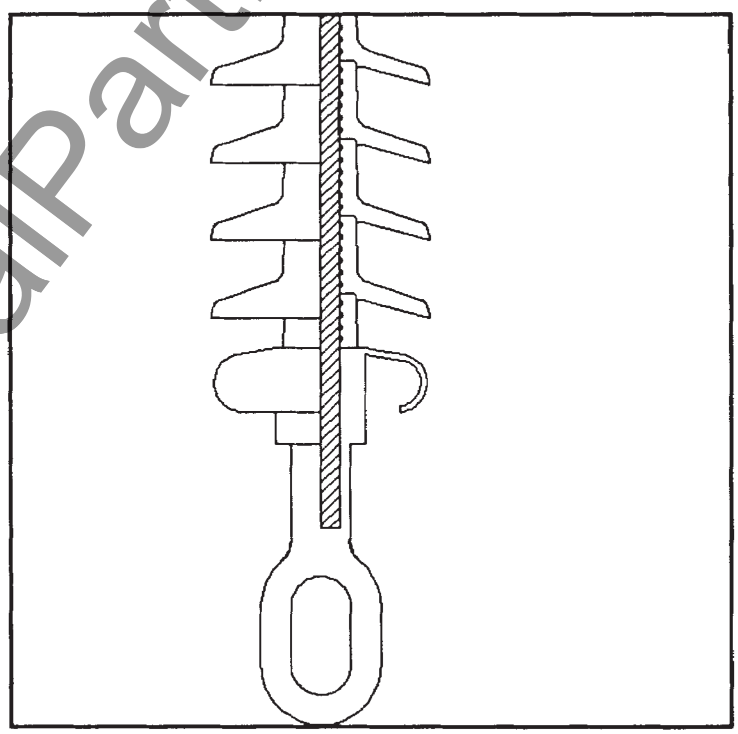

FIGURE 6 - HI*LITE II SUSPENSION

Also, a silicone compound was alloyed with the Dirigo 7345 compound. This alloyed compound (OBalloy 22) offered the mechanical toughness and resistance to tracking of EPM with the hydrophobic characteristics derived from the low molecular weight silicone oils.

In 1989, Ohio Brass changed the base material to EPDM, and increased the level of low molecular weight silicone oils in the alloy. This material is trade named ESP™ (Enhanced Silicone Protection).

The Hi*Lite II design's field history has been excellent. There have been no known mechanical problems to date. And we have had no materials problems with the OBalloy 22 or ESP compounds.

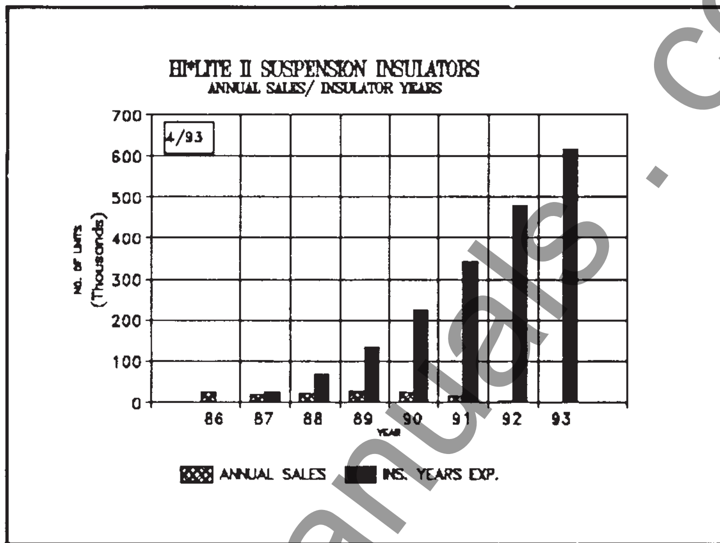

FIGURE 7

Since the introduction of Hi*Lite II in 1986, the design has compiled over 600,000 insulator years of experience without a field failure.

Following the introduction of the Hi*Lite II design, Ohio Brass was accused by many of offering a re-packaged version of the original Hi*Lite because the design enhancements were not obvious. At about the same time that the Hi*Lite II was introduced, Ohio Brass began the development of its third generation design, the Hi*Lite XL.

HI*LITE XL

- **FEATURES RETAINED FROM HI*LITE II**
  - ROD/RUBBER INTERFACE
    - REDUNDANT O-RING SEALS
    - SILICONE COMPOUND
      * HIGH RELIABILITY
  - EPOXY / VINYL ESTER ROD
    * HIGH STRENGTH/THERMAL STABILITY
  - CRIMPED END FITTINGS
    * NO POSITIONAL SHIFT
    * LONG TERM RELIABILITY
  - STRESS DISTRIBUTION HARDWARE
    * INTEGRAL GRADING
    * END FITTING / HOUSING SEAL
  - ESP - EP/SILICONE ALLOY - OBX141
    * HIGH LEVEL LMW SILICONE
- **NEW FEATURES**
  - MULTIPLE WEATHERSHED HOUSINGS
    - 4/8/12/16 SHED MODULES
  - MODULES MECHANICALLY SEALED
    - REDUNDANT CHEMICAL SEAL
  - HOUSINGS MECH. SEALED WITHIN CSR
    - BACK-FILLED WITH RTV

OH-6

FIGURE 8

HI*LITE XL: THE DESIGN

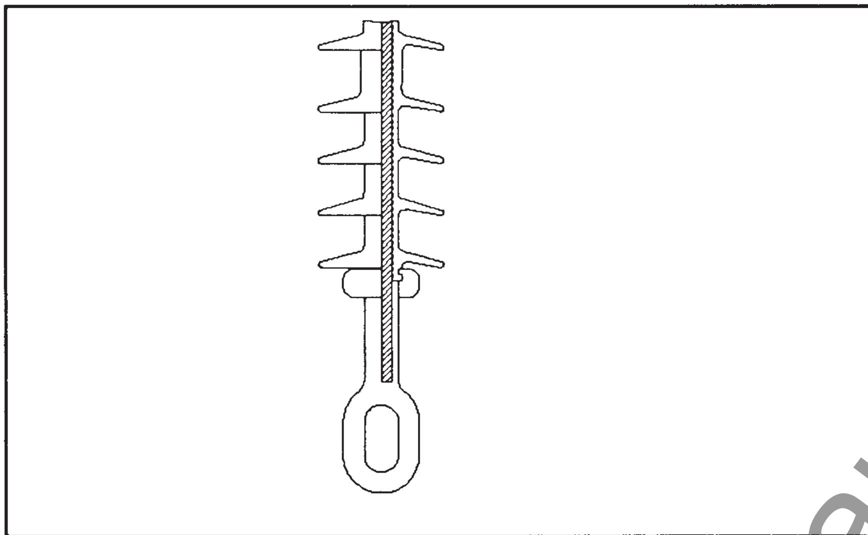

FIGURE 9 - HI*LITE XL SUSPENSION INSULATOR

Again, the perceived strengths and weaknesses of the Hi*Lite II design were reviewed. As a result, the XL product line uses the same silicone compound in the rod/rubber interface as the Hi*Lite and Hi*Lite II designs. The redundant o-ring sealing system at the rod/rubber interface has been retained to produce a dynamic dielectric seal. The rod types are the same as those used in Hi*Lite II. The crimping method was improved to provide higher ultimate strengths with greater consistency. The weathershed housing is composed of ESP, an EP/Silicone alloy, which was successfully used in the Hi*Lite II design.

The design was modified to utilize a sealed weathershed housing. This housing is molded in multi-shed modules, with each module mechanically bonded to the adjacent module by an external polymer collar. The modules are then mechanically sealed to the end fittings within an integral grading disk (see figure 9).

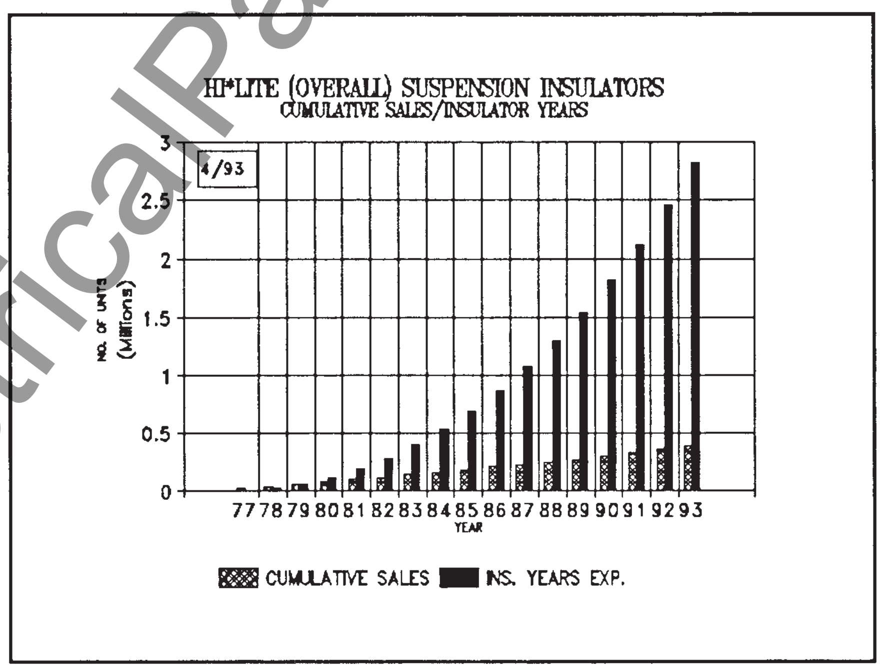

FIGURE 10

What has been addressed thus far is the manner in which the Hi*Lite product line has been improved over the last 20-plus years. Each change in design was carefully considered, and implemented only if it offered some improvement in the overall performance of the product. This philosophy has enabled Ohio Brass to gain almost 3 million insulator years of successful field experience to date.

POLYMER COMPOUND TESTING AND PERFORMANCE

There are two components of long term performance for an insulator -- material life and mechanical life. The two are intertwined.

Consider the materials. The long term performance of metallic parts are known and well documented. The fact that the fiberglass rod, which supplies the mechanical strength, must be protected from the weather to have a long life is also known. The usable life of the polymer is of primary concern.

There are 4 major degrading influences to a polymer material;

1) UV radiation
2) Heat
3) Oxidation
4) Mechanical Stress

It is Ohio Brass's belief that to make a true evaluation of a material, each of these degrading influences must be explored. The nature in which they are explored is also important. For example, if some special combination of these factors is tested. the result obtained is limited to that exact combination of factors and the most significant factor in the test may not be known. So the best picture is obtained with single influence testing. It is for that reason that Ohio Brass attempts to isolate these stresses whenever possible.

For UV radiation, Ohio Brass employs a QUV tester. This machine represents one of Ohio Brass's earliest test methods for polymer compounds. The test exposes the polymer to 16 hours of high

QUV TEST

- CYCLIC UV AND CONDENSATION (ASTM G53)
  - 16 HOURS UV
  - 8 HOURS CONDENSATION
- COMPARABLE TO DSET - 8 TO 13 TIMES ACCELERATION
- FAILURE CRITERIA
  - CRACKING OF THE SURFACE
  - CHECKING OF THE SURFACE
  - LOSS OF HYDROPHOBICITY

DATA

MATERIAL	TIME (HRS)
DIRIGO 7345 (LAO)	900
DIRIGO 7345 (HAO)	8000
OBALLOY 22	8500
ESP	27000+

+ TEST STILL IN PROGRESS

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FIGURE 11

intensity UV exposure followed by 8 hours of condensation at an elevated temperature. This exposure offers about a 10X acceleration factor over the sun in Florida, or about equivalent exposure to that offered by the Desert Sunshine Exposure Test. All samples are evaluated in terms of cracking, crazing, and loss of hydrophobicity.

Figure 11 contains some of the results. Ohio Brass is always attempting to improve the resistance of the compounds used in the Hi*Lite product line to this degrading influence.

Heat, as a degrading influence, is primarily available to a transmission line from the effects of dry band arcing on the surface of a material. Ohio Brass simulates this degrading influence with a tracking tester. An arc is initiated on the surface of the material by contaminating that surface and allowing dry bands to form. The arc should extinguish within 90 seconds if the material is intact. The failure criteria for this test includes the formation of holes, tracks, or the flow of current at the end of the 90 second time frame (see figure 12).

TRACKING TEST

- SAMPLES ON 30 DEGREE INCLINE
- ELECTRODES 35 mm APART
- 90 SECOND CYCLES
  - SPRAY NH_4Cl SOLUTION
  - ENERGIZE 10 kV
  - CONTROLLED 20 mA CURRENT
- FAILURE JUDGEMENTS
  - TRACK BETWEEN ELECTRODES
  - HOLE THROUGH THE SAMPLE
  - CURRENT FLOWS AT 90 SECONDS
- 5 SAMPLES TESTED - REJECT BEST/WORST

**** RESULTS ****

MATERIAL	CYCLES
PORCELAIN	50000+
DIRIGO 7345	50000+
ESP	38000
OBALLOY 22	20744

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FIGURE 12

Initially, Ohio Brass felt that a polymer should survive as long as porcelain. With continued experience with the dynamic nature of polymers, that requirement has been reduced.

Oxidation (the degrading effect of oxygen) is measured in a Differential Scanning Calorimeter. The temperature of a sample of the polymer is elevated in an inert atmosphere. Once the sample has reached thermal equilibrium, the atmosphere is switched to air. At that point, the sample is monitored for an exothermic reaction. This is a test of the effectiveness of the anti-oxidants and other additives used to extend the life of the polymer.

OXIDATIVE STABILITY

- MEASURE OF DISSIPATION OF ANTI-OXIDANTS
- SAMPLES HEATED TO 200 DEGREES C. IN NITROGEN
- ATMOSPHERE SWITCHED TO AIR
- MONITORED FOR EXOTHERMIC REACTION

DATA

MATERIAL	MINUTES
DIRIGO 7345 (L AO)	20-26
DIRIGO 7345 (H AO)	320+
OBALLOY 22	400+
ESP	400+

+ - TEST TERMINATED - NO EXOTHERM

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FIGURE 13

The results obtained by Ohio Brass (see figure 13) in this test indicate dramatic improvements in the ability of the polymer compounds to avoid thermal breakdown.

Because polymers are not typically mechanically stressed, Ohio Brass's fourth major development test for polymers involves a combination of several degrading influences. The test is intended to simulate corona cutting and is titled the Corona Cutting Test. Each sample is subjected to 300,000 micro-strain by bending it over a grounded electrode. Then a needle electrode is positioned 1 mm above the strained surface and 12 kV is applied. This generates continuous corona on the surface of the polymer. The polymer is subjected to UV radiation, mechanical stress, and oxidation from the generation of ozone all simultaneously. The test was devised to reproduce corona cutting observed on some insulators returned from the field.

The corona cutting test has been utilized extensively to guide Ohio Brass's development of new compounds. The ability of Ohio Brass's polymer compounds to withstand corona cutting has been greatly improved with each subsequent generation of the polymer (see figure 14).

CORONA CUTTING

- COMBINED STRESSES ON POLYMER SAMPLES
  - MECHANICAL BENDING STRESS - 30%
  - ELECTRICAL STRESS - 12 kV
  - UV DEGRADATION
  - OZONE

- SAMPLES BENT OVER GROUNDED MANDREL
- NEEDLE ELECTRODE 1 mm ABOVE RUBBER
- 12 kV APPLIED STRESS
- TIME TO SPLIT RECORDED

DATA

MATERIAL	HOURS
DIRIGO 7345 (L AO)	165
DIRIGO 7345 (H AO)	404
OBALLOY 22	1290
ESP	3000+

\+ - SAMPLE DID NOT FAIL

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FIGURE 14

All of the tests are accelerated to allow polymer compounds to be evaluated in a reasonable time frame. And still, it takes in excess of one year to develop the data to indicate whether or not a compound is suitable for use in Hi*Lite insulators. Figure 15 displays a bar chart comparison of all four tests with Ohio Brass's polymer materials shown in consecutive order of use: the original Dirigo 7345, Dirigo 7345 with higher anti-oxidant level, OBalloy 22 and finally ESP. The performance of each material is shown as a percentage of the best performing material within that test. Please note the improvements made to date.

Most of these tests have been developed in response to situations observed in the real world. How do the results correlate to the real world? The original Hi*Lite compound continues to survive after 17 years with minimal problems. Ohio Brass believes that today's ESP offers a significant improvement over that original compound. The fact that there has not been a single return of any insulator manufactured with either OBalloy 22 or ESP as a result of a failure of the polymer lends credence to that belief.

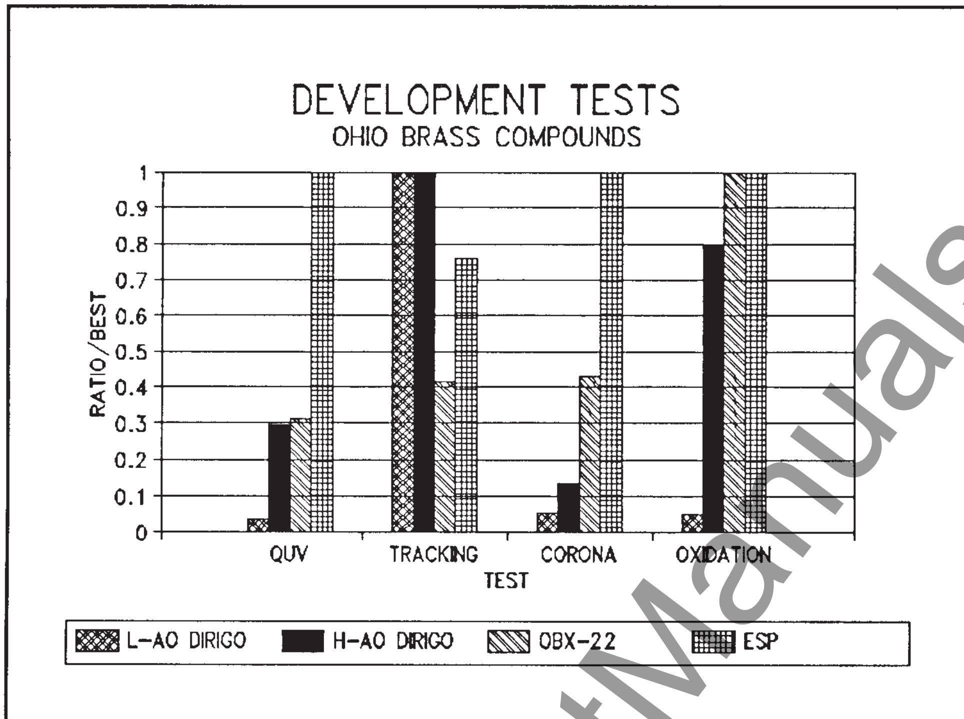

FIGURE 15

The other factor important to the life of an insulator, is its mechanical strength. These characteristics are usually referred to as the time-load characteristics. An insulator is a mechanical support. That is its primary purpose for existence. The electrical characteristics are added only if it provides the necessary mechanical strength.

Time-load deals with the ability of an insulator to support a given load for a long period of time. It is often confused with the ultimate strength of the insulator at any given point in time. The data plotted in figure 16 represents constant loads applied for some time period; in this case, until failure of the specimen occurs.

In other words, the insulator is loaded rapidly to a high level and then that load remains constant until the sample fails.

The curve (figure 16) represents data collected on insulators with a rod size equivalent to that used in Ohio Brass's current 25,000 lb SML insulators. The word "equivalent" should be emphasized. When these insulators were manufactured with a 5/8" diameter rod, the guaranteed minimum ultimate strength was 20,000 lbs. Each of the asterisks represent a failure point.

For the sake of completeness, a logarithmic regression has been performed on this data. That equation is shown on the plot. The correlation for time-load data is typically not very good, but it gives a general idea of the slope of the curve.

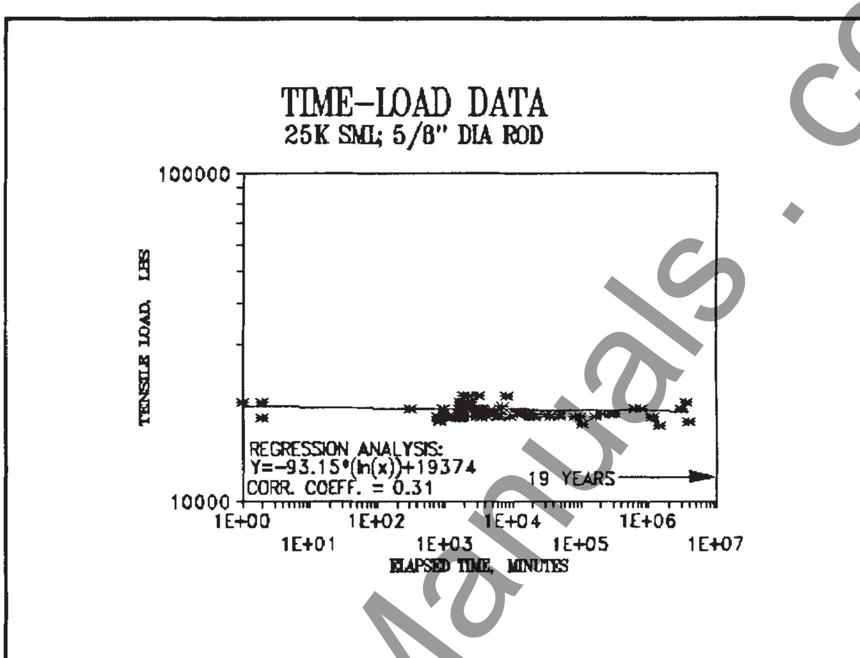

FIGURE 16

Please note that the regression line does not pass through the current SML for this rod size, nor does it threaten the RTL at any time in the foreseeable future. More than 95% of the insulators which fail in time-load testing are rod failures. What this appears to indicate is that the time-load test is a good measure of the capabilities of the rod used in the manufacture of the insulator.

Now, in contrast, consider a typical ultimate strength test. In place of the constant load used in the time-load test, there is a constantly increasing load.

When Ohio Brass began performing time load testing, an ultimate strength test was performed on every third insulator manufactured as a control group. Please bear in mind that these insulators were rated for an SML of 20,000 lbs, with an average ultimate strength of 25,000 lbs. The load was applied at a constant rate of rise until the insulator failed. The ultimate strength failures consisted of rod failures, hardware failures, and crimp slips (see figure 17).

If we consider the time load plot on top of the ultimate strength data, the ultimate strength data is not intersected by the projected curve from the time-load data (see figure 18).

Not only are the modes of typical failure different, but this would imply that the data are not related by a linear equation.

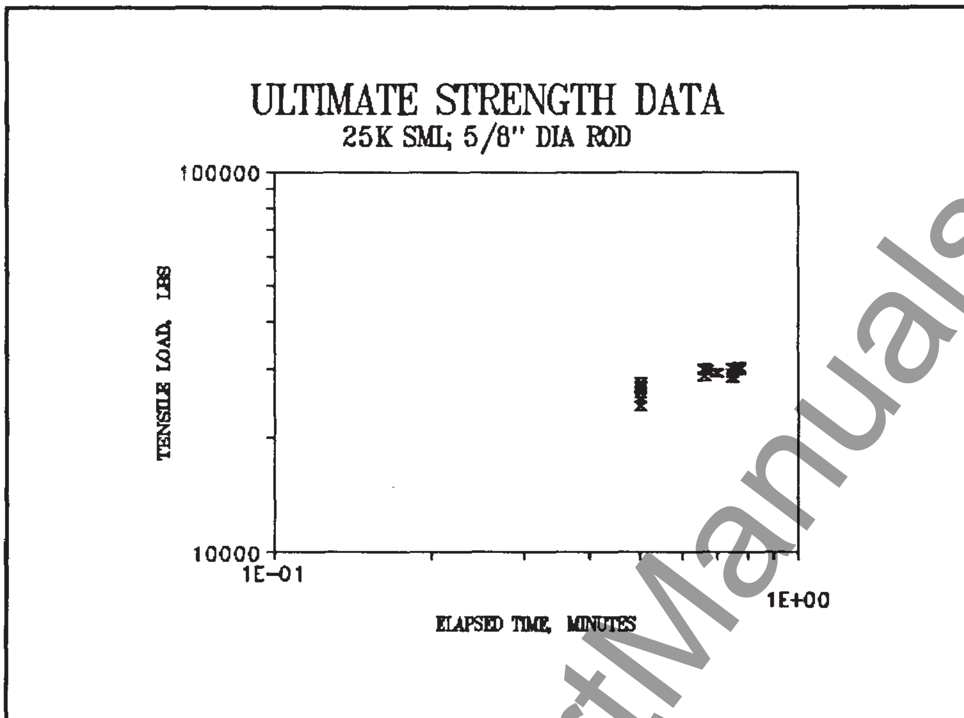

FIGURE 17

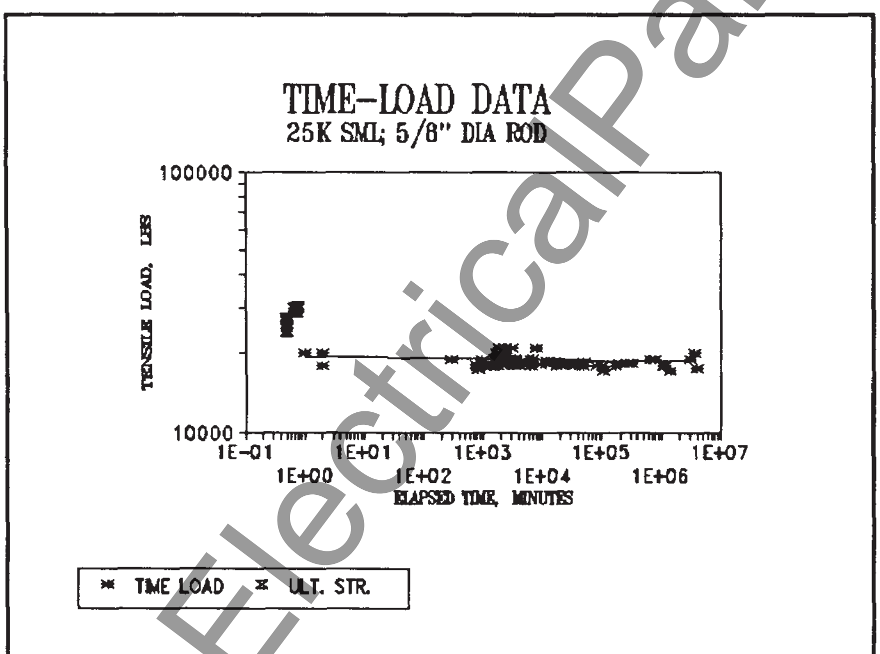

FIGURE 18

Why are time-load characteristics not related to the ultimate strength remaining in an insulator after a period of time in service. This really bears on the nature of damage progression in a time-load specimen. From a microscopic viewpoint, time-load characteristics are a result of flaws. For whatever reason, a glass fiber experiences a high stress and fails. This increases the stress on all of the surrounding fibers. As they fail, the situation repeats and a cascading effect occurs. This type of progression would imply an exponential rate of growth of the fracture. And this would logically lead to the conclusion that almost all of the damage occurs immediately prior to complete failure.

If that's the case, then a group of samples which are overloaded for an extended period of time should show almost no reduction in ultimate strength. To explore this, constant loads were applied to samples for fixed periods of time. Samples were usually loaded in groups of 5 or more. Attempts were made to remove the loads at a time immediately prior to the anticipated failure of the sample. In some cases, failures occurred on one or more samples, so the remainder were removed. Then an ultimate strength test similar to the SML test was performed on the samples removed from the test. Figure 19 shows the results of those tests. Each sample is represented by two points, vertically aligned. The lower point (the open box) is the time-load point. In other words if we read the x-axis, this is the time under load for the corresponding y-axis load. The upper point is the ultimate strength of that sample.

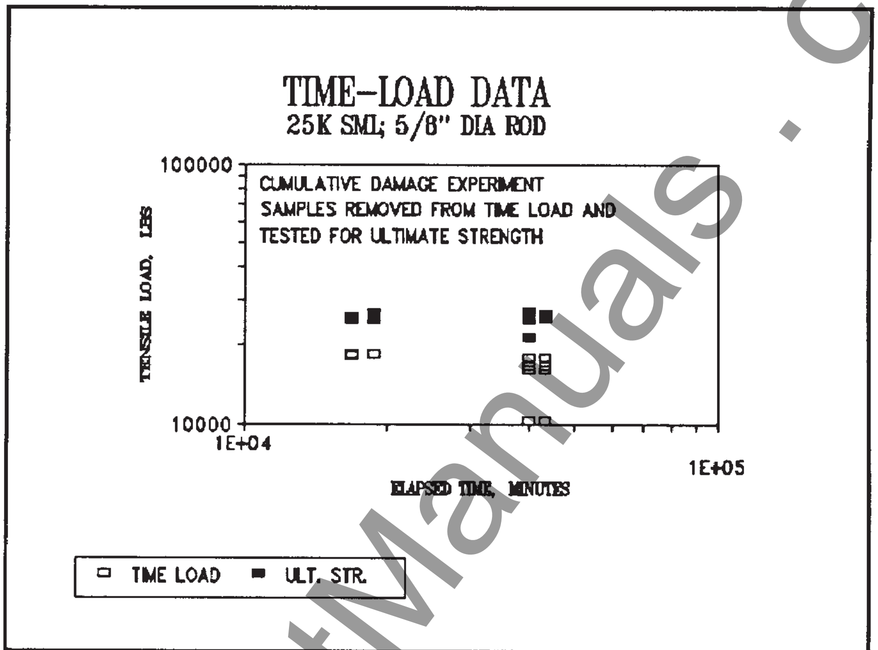

FIGURE 19

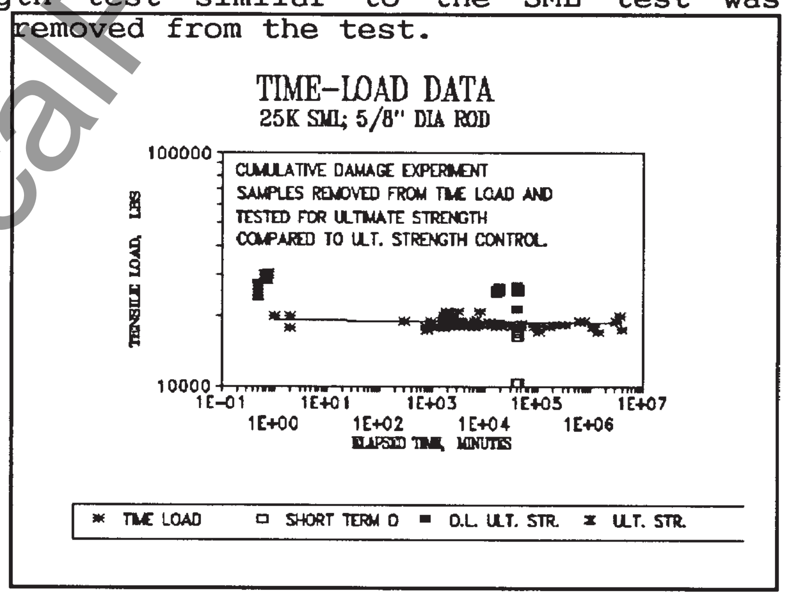

FIGURE 20

If figure 19 is overlayed onto the time load plot, you get a sense of our intent with this test (see figure 20). You can see how we tried to approximate the time to failure for the selected time load. The lower point for each data set is very close to the projected time load curve.

The ultimate strength data from the control group has been included in figure 20. The ultimate strengths after time-load are very similar to those of the control group.

This would seem to confirm that little or no damage had been done to the rod. Basically, the implication is that the damage does occur exponentially.

Testing is still underway. Using the data displayed, statistical inferences about the potential performance of insulators under load can be made.

Figure 21 displays the probability that a sample will have failed within a given time at a number of different loads. The lower the constantly applied load, the lower the probability of failure within any specified time.

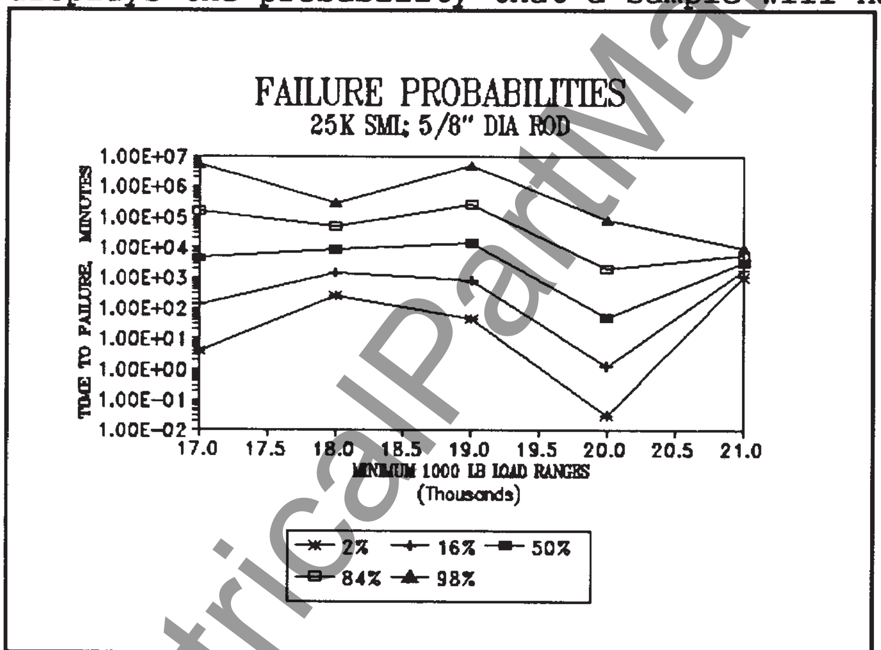

FIGURE 21

QUALITY

Thus far, this presentation has covered design changes made to improve the final product. The test program that Ohio Brass conducts to investigate the life of the polymer has been presented. And the time load characteristics have been examined.

Of even greater importance are the ways that Ohio Brass assures that the product you receive is of the highest possible quality. At Ohio Brass, we believe that quality must be front end loaded into a product. This contrasts with the philosophy that you can inspect quality into the product on the loading dock.

POLYMER COMPOUNDS
QUALITY ASSURANCE TESTING

° MOONEY SCORCH (3 PT. RISE @ 250 F. >3 MIN)
° MOONEY VISCOSITY (ML1+4 @ 250 F. = 35)
° OSCILLATING DISK RHEOMETER (ODR)
1. MIN. TORQUE - 7 LBF-IN
2. MAX. TORQUE - 115 LBF-IN.
3. SCORCH TIME - 0.86 MIN
4. CURE TIME - T_{c90} - 3.9 MIN
° MODULUS, 100% - 680 PSI
° ULTIMATE TENSILE STRENGTH - 1250 PSI
° ELONGATION - 190%
° DUROMETER/HARDNESS: SHORE A - 67
° SPECIFIC GRAVITY - 1.25

MOLDED PARTS
° ROUTINE VISUAL

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183A

FIGURE 22

What do we mean by inspecting quality into a product on the loading dock? Loading dock quality involves testing a product to assure it's good after it's made (on the loading dock). If it's bad, it's an expensive piece of junk.

But, if you carefully monitor all of the incoming raw materials and parts to assure that they are of good quality; if you utilize statistical process control to monitor each of your processes to assure that they are under control; and if you adequately train all personnel to properly operate their equipment, then you should produce a good product. And if some process or material deviation does occur, you will find it at the earliest possible moment, minimizing your investment in bad product. This method emphasizes "loading" the quality checks at the "front end" of the process.

How does Ohio Brass front end load their quality checks? For each batch of polymer received, the tests shown in figure 22 are performed. Many of these are fingerprint tests designed to point out any deviations from normal for the incoming material. Others are tests designed to determine proper cure cycles for processing. The remainder are tests of finished parts to double check the material and the processes.

The same process is pursued for the fiberglass rod purchased by Ohio Brass. All of the tests noted on figure 23 are performed on each batch of rod received. This is intended to assure that each batch meets our internal specifications.

FIBERGLASS ROD

QUALITY ASSURANCE

PHYSICAL CHARACTERISTICS

- ° RESIN POOR AREAS
- ° CRACKS
- ° FRACTURES
- ° FOREIGN MATERIAL
- ° EXCESSIVE SWITCHBACKS
- ° DIAMETER
- ° BARCOL HARDNESS
- ° POROSITY
- ° THERMO-MECHANICAL DEFLECTION
- ° CUT END DYE PENETRANT CHECK

MECHANICAL CHARACTERISTICS

- ° AXIAL TENSILE STRENGTH >100,000 PSI

ELECTRICAL CHARACTERISTICS

- ° DIELECTRIC STRENGTH - 60 HZ AXIAL 0.100" SPECIMEN, RMS >20 kV

OH-26
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FIGURE 23

Each batch of silicone compound utilized to fill the interface between the rod and rubber on the XL insulators is tested for bleed and evaporation in accordance with ASTM standards. Those levels must be maintained below 2%. The dielectric strength of the compound is sampled to assure that it meets our standards.

Ohio Brass's end fittings are swaged to a very tight tolerance on the outside diameter before drilling. Each drilled hole is gauged to guarantee that it meets dimensional requirements. Then the diameter across crimp flats is sampled and compared to SPC requirements for the dimension. This is intended to assure that the final product will meet all strength requirements. On top of that, set up tests are performed for every change of fitting type to be crimped and ANSI batch tests are performed in accordance with ANSI C29.11.

For Ohio Brass's low voltage Veri*Lite product line, the same demanding tests of polymer and rod are performed. The polymer utilized in these insulators is identical to that used in the Hi*Lite product line.

The Veri*Lite design employs a bonded interface between the polymer and the rod. Four samples per batch of Veri*Lites have the polymer stripped from the rod. Ohio Brass's specification requires that no less than 95% of the rod's surface have torn rubber on it. In this way, we assure the bond between the rod and the polymer is stronger than the polymer.

Again, we believe that if we perform the tests up front, we can minimize our losses and provide you with a better product. It's not a new concept, but it's one we're trying hard to perfect.

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