

Designing & Manufacturing Insulators: Not All Polymers are the Same [Part 1]

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Selecting and approving a polymer insulator supplier is a very complex proposition, this being so because not all polymer insulators are the same. While there are ANSI & IEC Standards that govern some aspects of polymer insulator design and manufacturing, there are more variations that are defined by each supplier that result in different looking and different performing polymer insulators. It is critical to understand these differences and how they impact the desired performance of the insulators. This Part 1 or 2 will describe the basic composition of the polymer insulator, reviewing the components and various options for these components, along with how they impact long term performance of the insulator. The paper will offer suggestions on how to specify the best materials, identifying critical details, words, and performance criteria above and beyond the standards. Finally, the paper will provide Facts and Comments on Polymer Materials which help define why all polymer insulators are not the same.

Common industry names for polymer...

- 1) Composite Insulator – (made up of various part, elements, or components)
- 2) Polymer Insulators
- 3) NCI – Non-Ceramic Insulator
- 4) Synthetic Insulators
- 5) Rubber Insulators

No matter what we call them, one aspect of a polymer insulator that is consist across all suppliers is the basic composition of the insulator: core, housing, and end connections. This is true at a very generic level. The forthcoming information will provide insight into what to look for and understand about how polymer insulators are manufactured and how those differences impact performance.

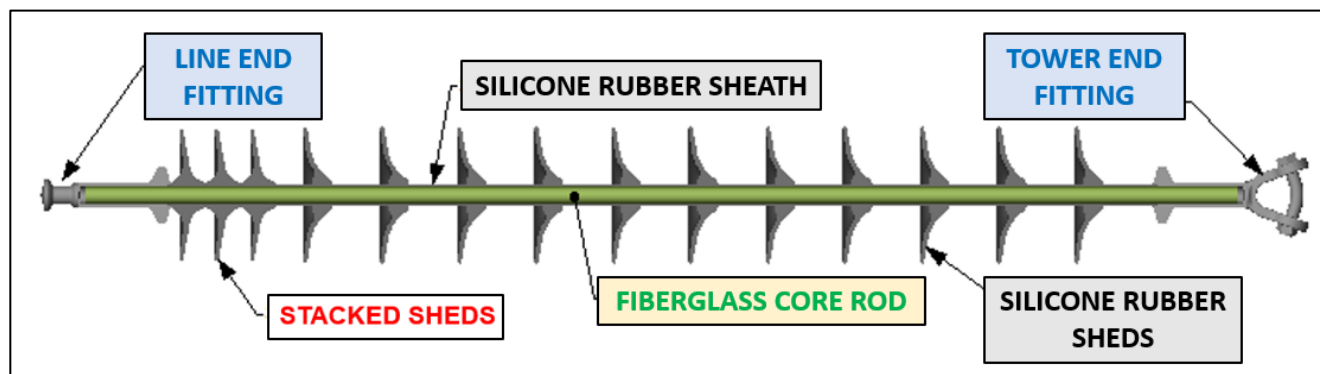


Fig. 1: Polymer Insulator Composition

Composition of a Polymer Insulator

- 1) Core – Fiberglass core rod, which is the heart of the polymer insulator, serving as both the primary mechanical and electrical component of the insulator. **[Green text in Fig.1]**
- 2) Housing – Typically a generic term for the sheath and weather sheds, most made up of either Silicone Rubber, or EPDM Rubber (and sometimes a combination of both). **[Black text in Fig. 1]**
- 3) End Connections – the end fittings, ductile iron or steel, connected to the core rod. The end fittings act as the mechanical connections through which the system loads are applied through the core rod to the tower. The insulator will typically have a Line end fitting (LEF), and a Tower end fitting (TEF). **[Blue text in Fig.1]**

Mechanical Performance:

The core rod when combined with two end fittings make up the mechanical element of the polymer insulator. An insulator is first and foremost a mechanical device, holding the conductor in space, maintaining minimum phase clearances as required by the applied voltage.

Tensile Applications:

- Suspension & Deadend Insulators.
- Small OD Core Rods [Transmission Class – 16mm, 22-24mm, 32mm, 38mm, and above]
- End fitting geometry governed by Standards (Most of the connection ends*)
- SML = Specified Mechanical Load = Rated Ultimate load
- RTL = Rated Tensile Load = Working Load [Standards define as 50% of SML but can vary by customer specification / definition for RTL ratings).
- Strength Rating not impacted by length of the insulator

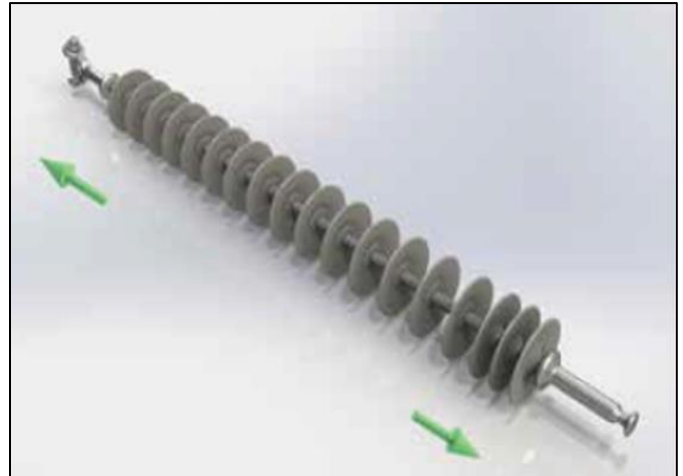


Fig. 2: Tensile Application

Cantilever Applications:

- Line Post & Braced Post Insulators
- Larger OD Core Rods [Transmission Class = 2.5" (63mm), 3.0" (76mm), 3.5" (88mm), and above]
- End Fitting geometry somewhat defined by standards, and typically requires some form of base connection to the tower.
- Post applications can be horizontal, vertical, underhung, and braced.
- SCL = Specified Cantilever Load = Ultimate Cantilever Load
- MDCL = Maximum Design Cantilever Load = Working Cantilever Load
- Multi-Axis Combined Loading – Vertical + Transverse + Longitudinal
- Post Applications require a Load Curve to define mechanical capacity [See Appendix A for more details of Multi-Axis combined loading & Load Curve definition]

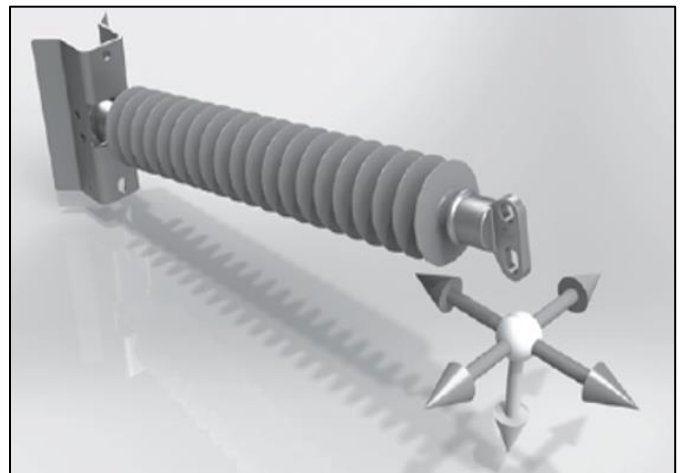


Fig. 3: Cantilever Application

Fact: As the Post get longer, it gets weaker (less cantilever capacity).

Fact: In a Braced Post application, the most common breaking limitation is dictated by the hardware and end fittings, not the core rod diameter – hence the need for Engineered Solutions & Testing.

**** For more specific details of mechanical loading, see INMR Papers from 2019:**

- *Longitudinal Loading – Fact vs Myth*
- *Maximizing and Validating Ultimate Capacity in High Strength Applications.*

Electrical Performance:

Once the insulator is mechanically stable, then it's second function is to provide the insulating properties to the insulator. The Fiberglass core is the primary insulating media, but only when fully enclosed within a rubber housing is the rod capable of performing the electrical functions of the insulator application. The most common rubber used to protect the fiberglass core rod; from moisture, contaminants, and any environmental stress; is silicone rubber. The housing consists of a sheath and weather sheds, which can be applied as one single body, jointed bodies, or modular process where the sheds are added to the sheath separately. No matter how the rubber is applied, the key dimensions to focus on when designing and comparing different insulator designs: Dry Arc Distance, Leakage (Creepage) Distance, Rubber (Insulating) Length, and Section / Connection Length.

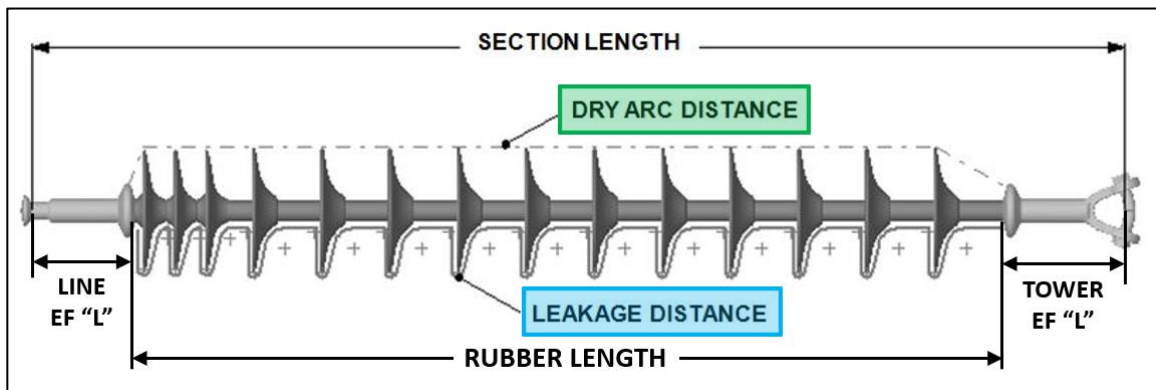


Fig. 4: Critical Dimensions of a Polymer Insulator

Critical Dimensions pertaining to Electrical Performance:

Dry Arc Distance: sometimes referred to as the arcing distance or flash-over distance, measuring the distance metal to metal, up to the first shed, across all the sheds, then from the last shed back to the end fitting. In simple terms, it is the air gap across the length of the insulator. (Highlighted in Green in Figure 4)

- Dictates the Dry Flashover & Withstand electrical values and CIFO (Critical Impulse) values.
- Wet Flashover & Withstand are determined by the dry arc distance, but impacted by the leakage distance, and shed profiles. (Performance of the insulator when wet and under continuous water application)
- All values above are statistically derived by each manufacturer, based on actual testing in a laboratory environment. The FO and Withstand values are nominal values, with a +/- range.
- The Dry Arc Distance is a measurable dimension that is fixed and can be used to compare different designs.

Leakage Distance: sometimes referred to as the creepage distance, is the distance across the surface of the housing (all sheds) from line end fitting to ground end fitting. (Highlighted in Blue in Figure 4)

- Protects the insulator from the impact of contamination, and harsh environments
- Leakage is also a dimension that can be used to compare different designs.

Section Length: or connection length is the distance from line to tower connection of the insulator.

- Subject to change based upon the type of end fittings used.
- While the section length is critical, it is second to the Dry Arc distance when comparing insulators for electrical performance.

Rubber Length: or minimal insulating length is the distance of the rubber housing, from end fitting to end fitting along the X axis.

- This dimension is defined by the Manufacturing Equipment, and once defined by the supplier, is not likely to change.
- The Rubber Length is a reference dimension that is less critical to the performance of the insulator.

Fact: The best way to increase the dry arc distance is to increase the section length, with each added inch of section length, the dry arc distance increases by an inch. One for one relationship.

Fiberglass Rod Core – The Heart of the Polymer Insulator

The fiberglass core rod is both the primary mechanical and electrical component of a composite, making it the “Heart of the Polymer Insulator”. The core rod is made up of thousands of individual glass fibers (called roving’s) that are bonded together by an epoxy resin.

The Fiberglass Manufacturing Process

- 1) Individual fiberglass fibers on creels, pultruded thru a series of resin dips (baths).
- 2) Resin coated fiberglass strands pulled through a rod sizing die.
- 3) The sized rod is cured and then cut to length (as required)



Fig. 5: Fiberglass Core Manufacturing

Fiberglass Core Composition

The fiberglass core rod is made up of resin impregnated fiberglass, but the type of resin and fiberglass, along with the percentage of glass vs resin is not defined in a standard, these decisions are left up to the rod manufacturer to define. The decision on what glass and what resin could depend on intended mechanical and electrical performance of the rod. For example, a smaller OD core rod is primarily used for tensile applications, where a larger OD core rod is required to meet higher compression and cantilever mechanical loads.

Fiberglass “Fiber” options: both meet or exceed the defined tests in both ANSI and IEC Standards

- 1) E-Glass = Electrical Grade Fiberglass
 - Primarily used today to MFG Line Post core rods
 - Used on early generation polymer (suspension)
 - Susceptible to Brittle Fracture (on Suspensions)
- 2) Corrosion Resistant E-Glass (CR-E or ECR) = Boron Free Fiberglass
 - Removed Boron Oxide from composition of glass fibers
 - Designed to eliminate Brittle Fracture (see Appendix B for more on brittle fracture)
 - MFG the same as standard E-Glass
 - Mechanically & Electrically equal to E-Glass

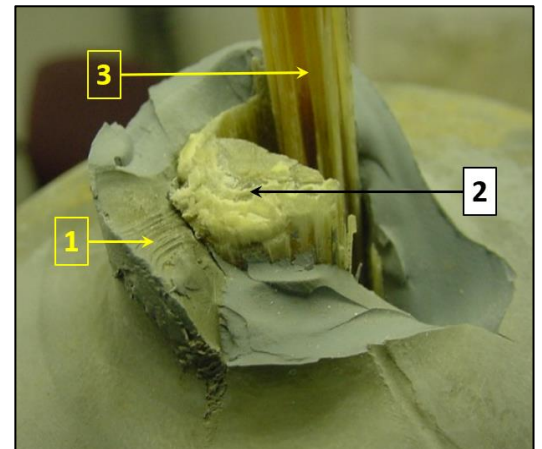


Fig. 6: Brittle Fracture Example

Resin options: all meet or exceed the defined tests in both ANSI and IEC Standards

- 1) Epoxy Resin = high electrical insulation, mechanical strength, and resistant to chemicals. The finished rod is potentially more brittle, impacting the crimping process, and may experience issues due to high temperatures used during the next step in the manufacturing process, application of rubber housing.
- 2) Polyester Resin = lower cost resin, but also less chemical resistant. More ideal for marine application.
- 3) Vinyl Ester / Epoxy Blend = combines the best features of polyester and epoxy resins. The combined material (hybrid) is stronger than polyesters and more heat resistant than epoxies, making it ideal for both application of rubber and crimping.

Fiberglass Core Rod – Make or Buy?

There are polymer manufacturers that make their own rod, and others that purchase it as a finished good from a 3rd party supplier. In most cases, even the suppliers that make their own rod have a 3rd party supplier approved to supply rod as a back-up to their own supply. It is a good practice to have multiple approved suppliers in case of emergency and or for expanded capacity.

Typical Range of Core Rod Diameter by Application

- **Tension Application (Suspension Insulators)**
 - 16mm – 38mm Core Diameters – most common sizes
- **Cantilever / Compression Application (Line Post Insulators)**
 - 1.5" – 3.5" Core Diameters – most common sizes
 - Hollow Core Rods



Fig. 7: Fiberglass Core Rods

Comment: Manufacturing the fiberglass core rod is a very messy process, one that is best performed in its own plant, separate of the MFG of the finished polymer insulator. Even when a manufacture makes their own rod, they typically do so in a separate factory, or building away from the MFG of the polymer insulator.

Evaluating Quality & Performance pertaining to the Core Rod:

- The performance of the rod (MFG or purchased) with respect to the Standard Tests
- How is incoming (self-produced and 3rd party) rod inspected and approved for production?
- Does the manufacturer have lot control? Are they able to trace rod all the way through production to the completed polymer insulator?
- Do they use “Boron Free” core rod for suspension applications?
 - *** This should be a standard offering, only CR E-Glass is used for Suspension MFG.
 - *** Not ideal practice to offer both E-Glass and CR-E, too easy to confuse and use in wrong application

Rubber Housing & Weather Sheds:

The function of the rubber housing, in conjunction with the weather sheds protects the core rod from the impact of the environment (including salt, dirt, dust, and moisture) the insulators are used in. Historically, the rubber housing may have been made up of different materials, silicone, EPDM, and Alloy materials.

EPDM [ethylene propylene diene monomer] Rubber

- Organic Backbone of “C-C”, Carbon – Carbon molecular bonds = Low Bond Energy
- Susceptible to UV Degradation (Embrittlement and cracking of the rubber)
- Starts out Hydrophobic but loses it over time.

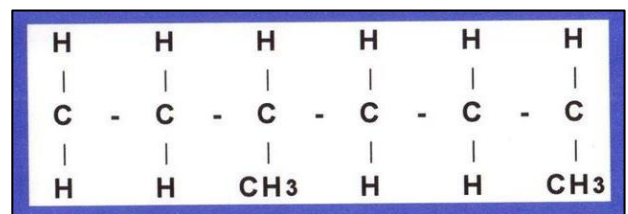


Fig. 7: EPDM Chemistry

Alloy Rubber

- EPDM based material with silicone oils added to the formulation to assist with Hydrophobicity and UV resistance.
- Ultimately, this blend did not provide the best of both materials, but rather defaulted to the worst of both and did not have the long-term benefits of just using silicone.

Silicone Rubber

- Inorganic Backbone “Si-O”, Silicone – Oxygen molecular bonds = High Strength & very stable
- Maintains Hydrophobicity and can recover hydrophobicity after an electrical event.
- Unique ability to encapsulate contaminants, rendering that surface hydrophobic.

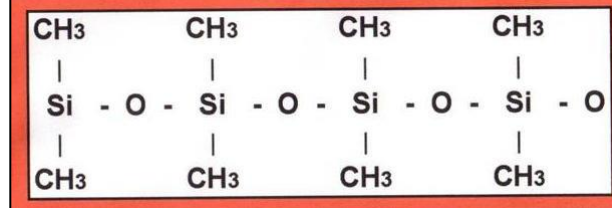


Fig. 8: Silicone Chemistry

Not all Silicone Materials are the same, the quality and performance of the silicone is based on the formulation and the manufacturing process by which the rubber is vulcanized (transitioned from raw to cured state).

A. Silicone Formulation – Each supplier uses a “Proprietary” Silicone Formulation as part of their insulator design.

Each formulation is a mixture of insulating materials, compounded as required by the supplier.

- Fact: Just because it is silicone, does not equal to quality and proven performance! This will vary from formulation to formulation, which each supplier should be prepared to discuss when asked and should have test documentation to prove their formulation will meet expectations.
- Specific % of each component is again specific to each supplier and may vary in performance of that formulation. Too much or too little of one component of the formulation could be the difference between good performance and poor performance.
- **Basic components of a Silicone Formulation**
 1. Base Material = Elastomer or pure silicone, base polymer that is the backbone (Si-O) of the formulation, responsible for Hydrophobic performance [Hydrophobicity over the life span of the insulator, Hydrophobic recovery rate, ability to encapsulate contaminants]
Hydrophobicity = ability to repel water
 2. ATH [Aluminum Tri-Hydrate] is the arc resistance agent in the formula to improve tracking and erosion capabilities.
 3. Curing Agents – crosslinking catalyst or accelerators that trigger the vulcanization process, which begins to cure the silicone into its finished state.
 4. Color – Silicone is typically clear, so grey coloring is added to the compound.
 5. Processing aids / Mold release agents – help material flow in molds and adds good release properties.
 6. Special Additives / Fillers – as defined by each supplier.



Fig. 9: Silicone Hydrophobicity



Fig. 10: Aged / Cracking Rubber

B. Processing Type [Different methods of vulcanizing / curing the raw rubber into the finished material]

- HTV = High Temperature Vulcanize = process by which heat is applied to adhere a rubber material to the core rod surface, curing the rubber as it is applied.
 1. Most used in the following MFG processes, injection molding, extrusion, and compression molding.
 2. HTV Silicone is the most used material & process in the industry
 3. HTV Silicone has the longest proven performance history (both in lab testing and field experience)

- LSR = Liquid Silicone Rubber – a two component system (A & B), used primarily for its ease of injection and filling mold tooling.
 1. Less used MFG process for insulators, and not as proven as HTV.
 2. Historically there have been deficiencies in LSR based insulators (related to performance)
 3. Most common use is for Medical and Automotive applications
- RTV = Room Temperature Vulcanize
 1. Silicone rubber that cures at room temperature (no added heat like HTV)
 2. Applied like a bathroom caulk.
 3. Used as part of some sealing processes, but RTV does not provide the long-term performance of an HTV Silicone.

While LSR technology is improving and becoming accepted in the industry, the more conservative approach is to continue using the HTV Silicone technology, simply because it has the longer history and proven performance. When evaluating LSR vs HTV, it is critical to consider Risk vs Reward, and focus on which material will provide the long-term performance expected of the polymer insulator.

Recommendation: Use a Silicone Materials with a proven formulation, vulcanized / processed using an HTV manufacturing process.

Evaluating Quality & Performance pertaining to the Rubber (Silicone) Material:

- Testing of the Rubber Materials to the industry required standard tests.
- Ideally, the polymer supplier being considered uses a Silicone Rubber HTV Material.
- Since the formulation of the silicone most likely would be considered proprietary (secret recipe), the supplier should be prepared to present to the customer what their formulation consists of and why the specific formulation is being offered.
- Do they have test data and history to support this formulation?
- How does the manufacturer inspect incoming materials? Is it certified by the sub-supplier?
- How is each lot of material lot coded and can each lot of material be tracked through production?

Comment:

An Electrical grade core rod with a silicone housing is an **insulator**.

An Electrical grade core rod without a silicone housing is an **isolator**.

Guys Strains & Brackets with painted or veiled rod do not have the insulating protection of a silicone coated design.

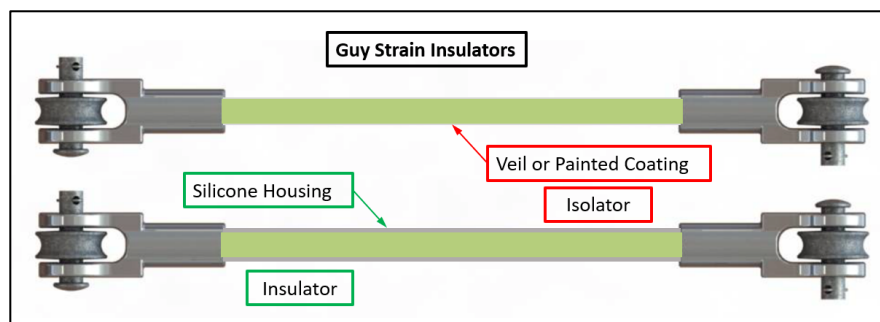
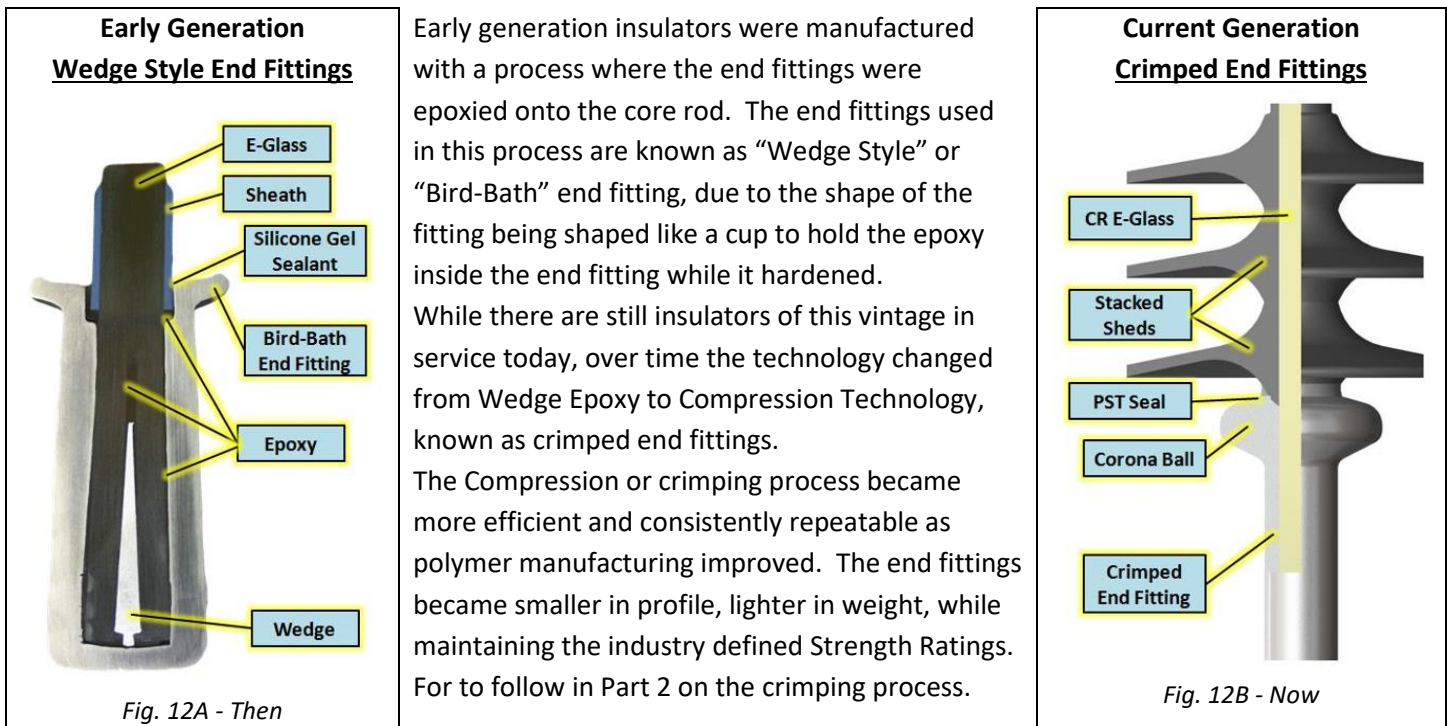


Fig. 11: Guy Strains

End Fittings:

The metal components attached to the ends of the polymer insulator are called end fittings. Depending on the strength rating (SML) of the insulator, these end fittings could be made of ductile iron or steel. The higher the SML, the more likely the end fitting is some form of steel, either case or forged. Both iron and steel are then finished in a galvanize coating, which protects the metal from the effects of the environment, resulting in rust and corrosion.



Like all other parts of a polymer insulator, not all end fittings are the same. The connection types of the end fittings are common, and most are well defined by standards. But the end fitting barrel is fully defined by each supplier.

Connection Types [ANSI & IEC]

- Socket & Ball (Most defined set)
 - ANSI 52-5 (30k), 52-8 (40k), 5-11 (50k)
 - IEC 16 (120kN), 20 (160kN & 210kN), 24 (300kN), 28 (400kN), 32 (500kN)
- Y-Clevis / Ball (Most common in US)
- Oval Eye / Oval Eye
- Clevis / Tongue (Well defined set)
- Clevis / Clevis

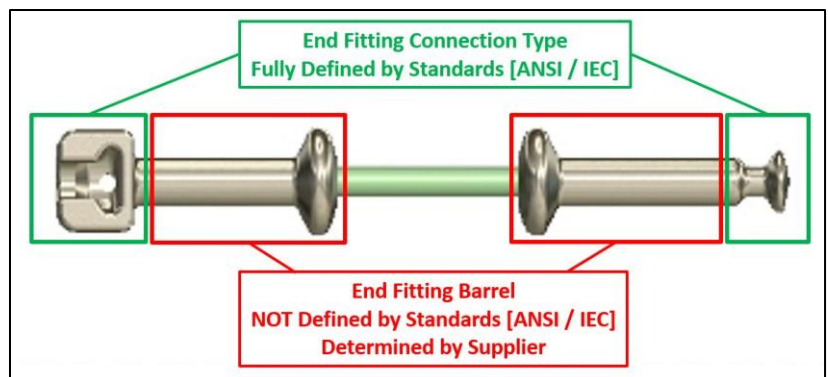


Fig. 13: End Fitting Design

The connection ends of the I end fittings are mostly governed by standards and gauges. Some are more defined and complete than others, and some do not have gauges. The most defined set of end fittings would be the socket and ball connections, which whether ANSI or IEC are fully defined by Go & No/go gauges. Second to the socket and ball would be the Clevis / Tongue or Clevis / Clevis set of end fittings, which are also well defined, but used primarily for International applications, and at times they can have nonstandard SML ratings. These would be defined by the customer in their specification.

Fact: In the US, the most common set of end fittings used are Y-Clevis / Ball for suspension, and Oval Eye / Ball or Oval Eye / Oval Eye for Deadend application.

While the connection type of the end fittings is more common and defined by standards, the remaining connection geometry of the end fittings, sometime referred to as the barrel, is defined 100% by the individual polymer manufacturer.

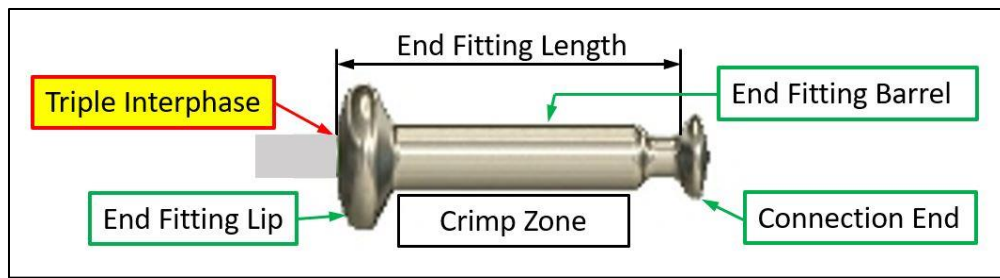


Fig. 14: End Fitting Barrel Details

The end fittings, aside from the connection geometry, has many differences

1. End Fitting Length – the length of each end fittings is determined by the connection geometry and the design of the end fitting barrel. It is likely that the barrel geometry for each end fitting will be the same for each strength class, but when combined with the different connection types, the end fitting length varies for each connection type.
2. End Fitting Barrel – The length and OD of the barrel of the end fitting are driven by the crimp zone and crimp technology used by each manufacturer. The geometry of the crimp zone fluctuates based on the amount of material displacement required to attain a desired SML rating. More detail on crimping will be covered in Part 2 of the paper.
3. Crimp Zone – area along the length of the end fitting with manufacturing clearances on both ends of the end fitting to allow for proper compression of the end fitting.
4. End Fitting Lip – This is the end of the barrel opposite the connection end, and the designs vary the most here. Some designs may have very small radii at the ends, while other designs may have a greater mass of metal making up the lip or corona ball.
 - The reason for the corona ball or larger lip is to prevent exposure of the core should an arc terminate on the end fitting. In the event of arc termination, the corona ball would be able to withstand multiple impulses without breaching the end fitting triple interphase.
 - The larger lip is called a corona ball because it is designed to act like a small OD corona ring, providing protection from e-field stresses at the triple interphase.
 - Finally, the corona ball feature can be the mounting geometry for a corona ring.
5. Triple Interphase – this is the area of the polymer insulator where the rod, rubber, and end fitting all meet, and in most designs is also the sealing mechanism of the insulator.

Fact: The end fitting length impacts the insulator section length the most. The customer can match a length and make the dry arc distance variable, or they can use the dry arc distance (rubber length) which would then make the section length variable. Ideally this is covered in a specification $\pm$ tolerance range.

End Fitting Procurement:

Like the pultrusion of the core rod, it is unlikely for the casting, forging, and galvanize process to take place in the same factory the insulator is assembled. End fittings are typically sourced, depending on the supplier and their location. For insulator MFG in the US, all transmission class end fittings are sourced from various countries, including China, India, Mexico, and Brazil.

Fact: the manufacturer of a polymer insulator should do their own investigation and approval of each potential end fitting supplier as part of their internal quality system. It is unlikely that a supplier will cut corners on quality on end fittings, seeing how critical they are to the finished polymer design and performance.

Evaluating Quality & Performance pertaining to the End Fittings:

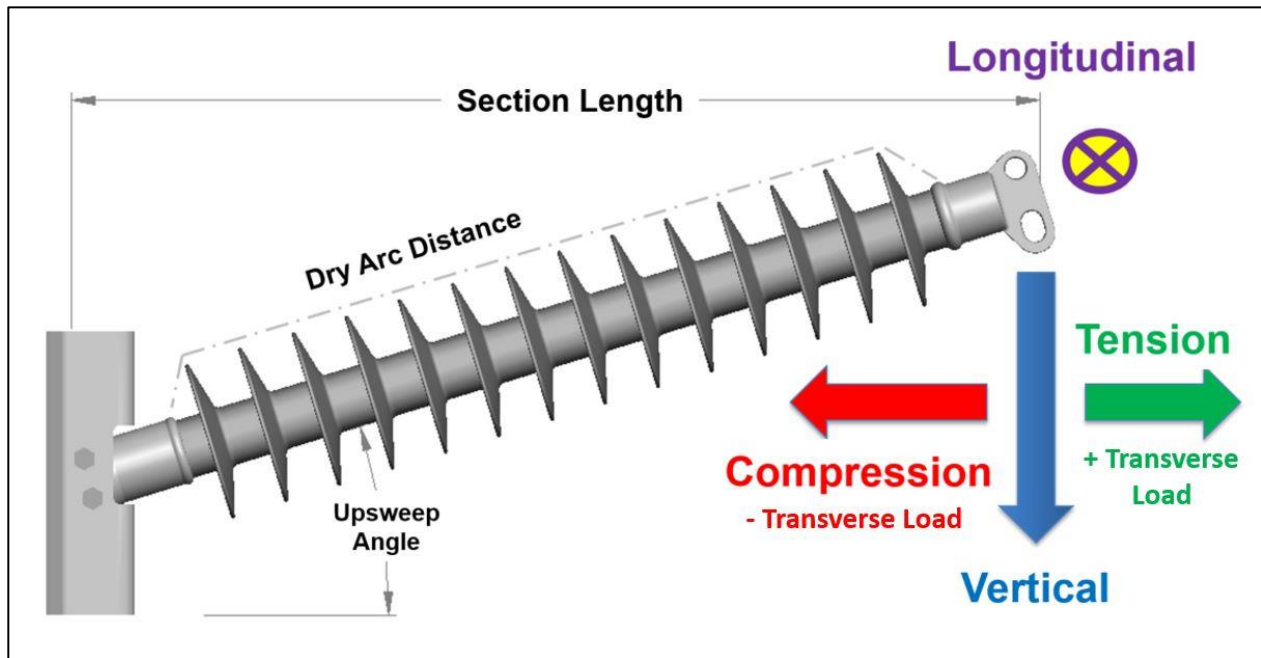
- The polymer supplier should be prepared to present a complete evaluation and quality documentation for each approved end fitting sub-supplier.
- The supplier should present how they design and use their end fittings as part of the polymer insulator, including how the end fitting design may or may not impact the corona ring design and application.
- Like all materials, the country of origin should be marked on the end fittings.
- The supplier should have a defined lot control process, with the ability to track these lot codes to the production of the finished insulator.
- The supplier should provide documentation on how the end fittings are qualified, which may include ultimate strength ratings (which may be part of the crimping process).

Conclusion Part 1:

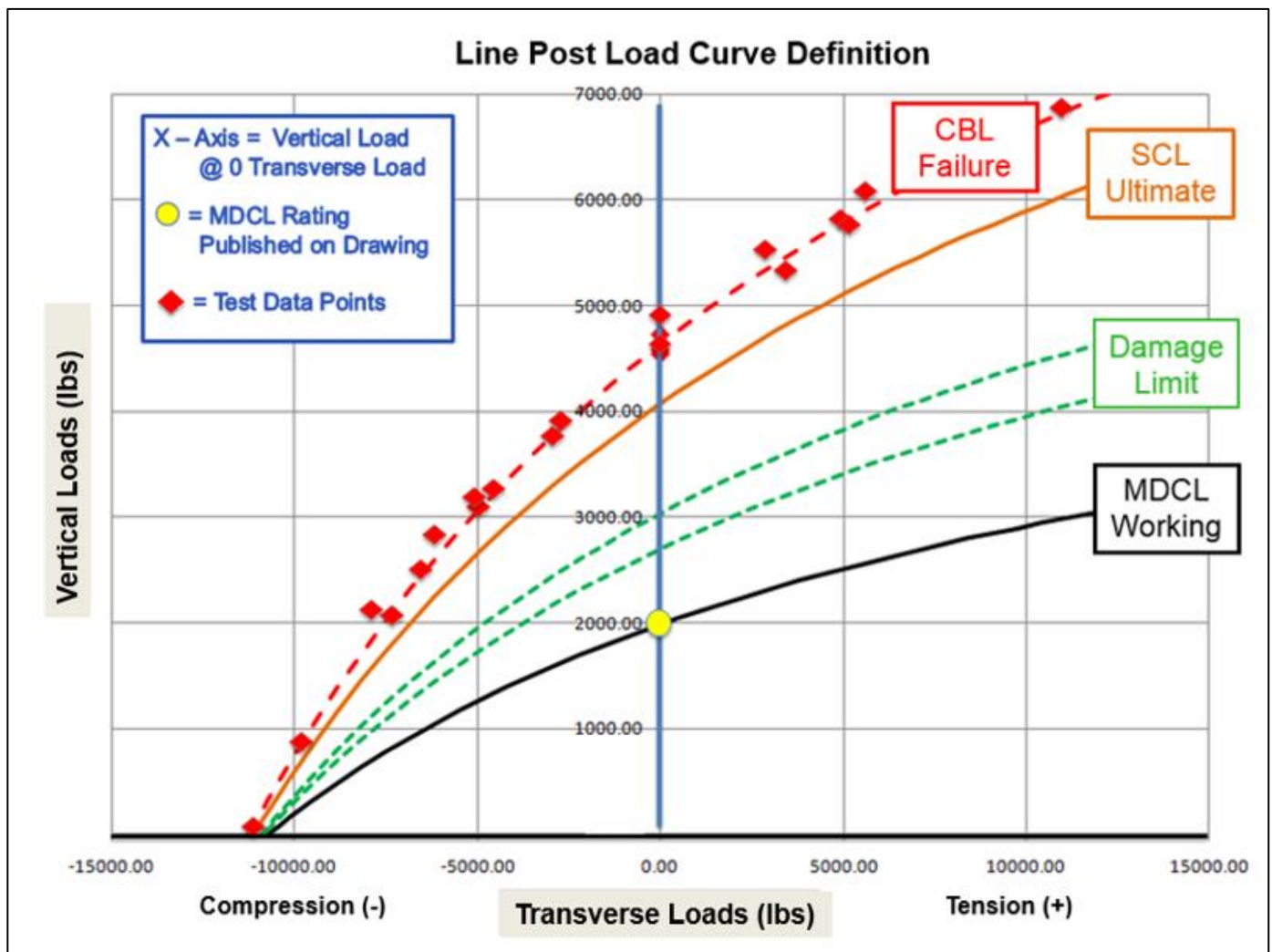
The process of evaluating polymer insulator designs is very difficult, and the various material options do not make the process any easier. The customers are smart to use the governing standards to assist in determining which designs meet their needs, but the standards are not enough. The customer should have a very robust and detailed specification, defining performance criteria, and knowing which materials to require and what dimensions to make critical. Knowing what the various material options are and how they impact performance is vital for a customer to be able to make good evaluation of each supplier.

To be continued in Part 2 of this paper.

Appendix A: Multi-Axis Combined Loading & Load Curve Definitions



Multi-Axis Loading Definition

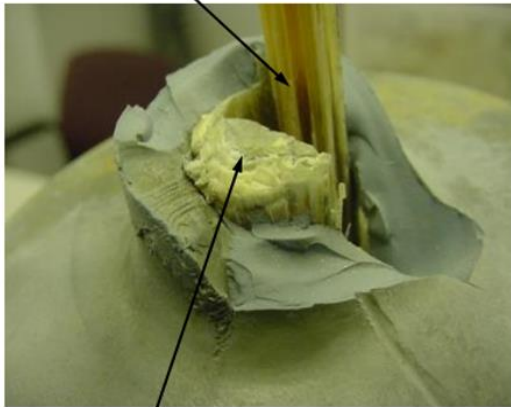


Load Curve Example

Appendix B: Brittle Fracture

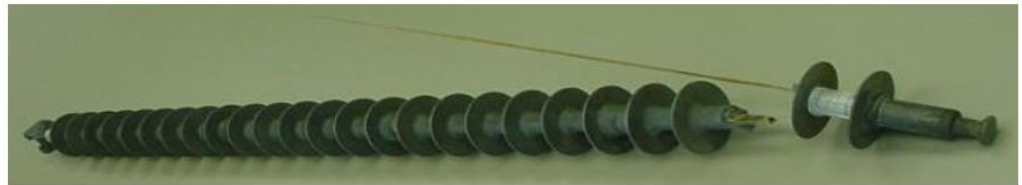
Reference – “IEEE Task Force Report: Brittle Fracture in Non-Ceramic Insulators” (2002)

Fractured Surface

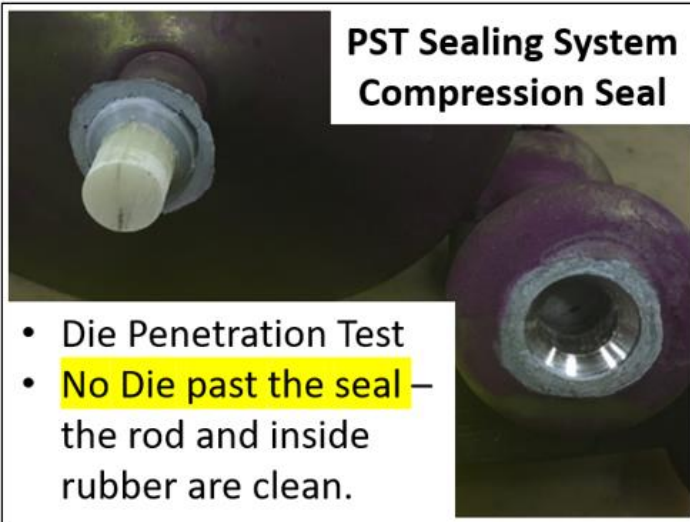


- Brittle Fracture typically is an issue for suspension / tension insulators, no reported BF of Line Post Insulators
- Results in a complete separation of the line end of the insulator
- Brittle Fractures usually occur within (5) Years of Energization
- Frequency of Occurrence = Less than 1 in 10,000
- 1/3 of all reported Brittle Fractures attributed to end user influence. (*installation damage, vandalism, gun shot, etc.*)
- The other 2/3 were attributed to insulator design; poor housing quality or bad sealing system (no seal)
- There are no methods to ID a potential BF failure.

Planar Surface

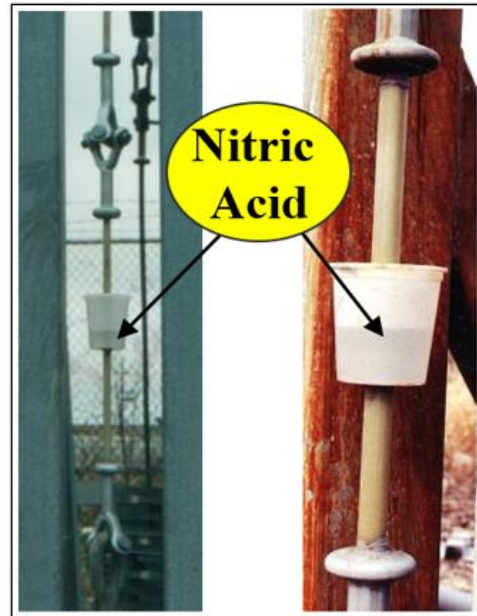


PST SEAL SYSTEM + CR E-GLASS
= **Elimination of Brittle Fracture**



**PST Sealing System
Compression Seal**

- Die Penetration Test
- **No Die past the seal** – the rod and inside rubber are clean.



<u>Glass Type</u>	<u>Time to Failure</u>
E-Glass	< 96 Hours (Service)
CR E-Glass	> 15,000 Hours

- CR E-Glass = Boron Free
- E-Glass Failure < 8-10 Hours (Test)