

Designing & Manufacturing Insulators: Not All Polymers are the Same [Part 2]

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Now that we have a better understanding of the composition of a polymer, this leaves the Manufacturing process and Quality Assurance as the focus of Part 2. Once again, we have a variety of manufacturing processes by which a Polymer insulator can be made, and again, very little is defined in standards defining for the supplier or user on what to us and why. Each supplier chooses the process or multiple processes that they feel is best to service their market. In some cases, the resulting finished insulators perform the same, but will look very different. The objective of this paper is to provide insight into these different manufacturing processes, identifying pros and cons of each, and ultimately helping the reader better understand what to look for when conducting an audit or approval of each supplier. Not All Polymers are Made the Same Way!

Design Assumptions:

To maintain focus on the most common and historically used manufacturing processes, the following assumptions on materials were selected.

- Material – Silicone Rubber (Non-specific Formulation)
- HTV curing of silicone
- There are 5 basic MFG processes to make a Polymer Insulator

Manufacturing of Polymer

- 1) Core Rod
- 2) Application of Rubber
 - A. Housing / Sheath = rubber applied to the core rod
 - B. Shed Profiles = Dry Arc & Creepage / Leakage Distance
- 3) Attachment of end fittings to the core rod.
- 4) Method of sealing the rod, rubber, and end fitting at the triple interphase point
- 5) Design & Application of Corona Rings

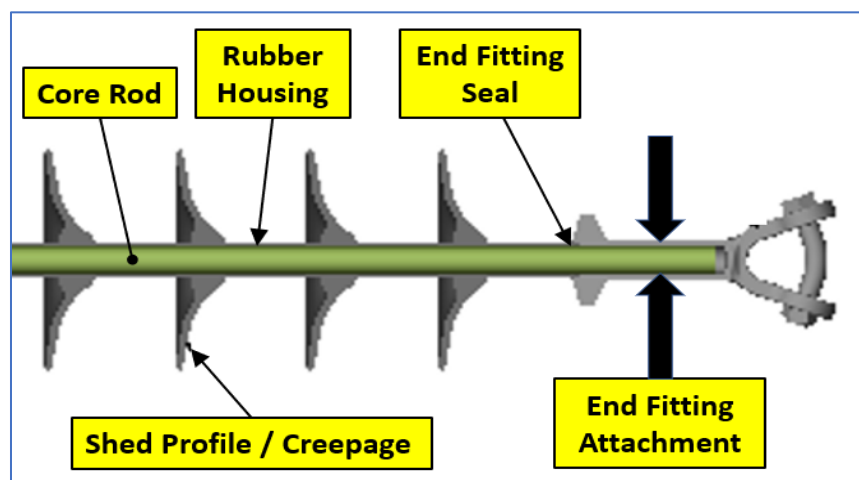


Fig. 2-1: Polymer Manufacturing {Key Terms}

1) Core Rod

For this paper, we are assuming the rod is procured from a 3rd party supplier, so the details that follow are not specific to one rod manufacturer, and most likely used by multiple polymer suppliers.

Suspension & Tension Insulators:

Insulators that are used primarily in tensile applications, whether they be deadends, suspension, or angle applications. Tensile Ratings (SML) pertaining to the core rod are determined by the OD of the rod.

Rod OD	SML Rating	
	lbs	kN
16mm	25k-30k	120
18mm - 22mm	36k-40k	160
22mm - 24mm	50k-60k	210 - 300
32mm	80k-90k	400
38mm	120k	500

Fig. 2-2A: Tensile Ratings by Rod OD

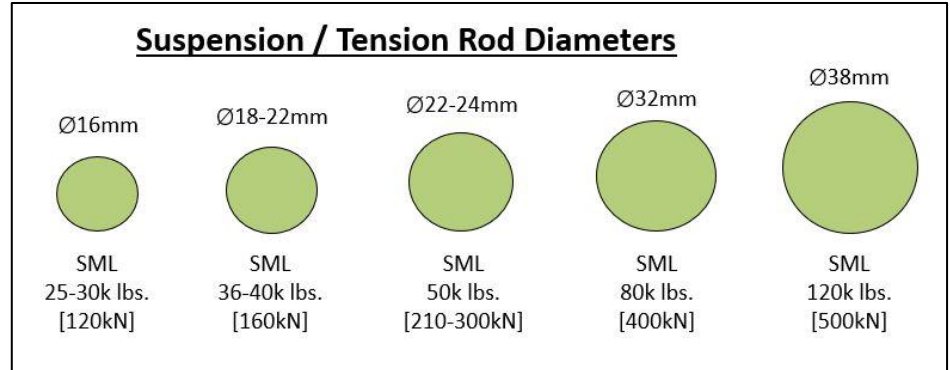


Fig. 2-2B: Common Suspension Rod Diameters (Not to Scale)

Facts & Comments:

- Primarily Tensile Load – Simple
- SML – Specified Mechanical Load [Ultimate Rated Tensile]
- RTL – Rated Tensile Load [Working Tensile Load] – Typically 50% of SML by Standard
(RTL may be defined by Customer Specification to be different % of SML)
- SML not limited by length of the insulator
- Recommended to use CR E-Glass Rod [Boron Free] to mitigate effects of brittle failure

Line Post Insulators:

Insulators typically used in cantilever applications, whether they be Horizontal or Vertical Posts.

Rod OD	Typical Voltage
1.5"	15kV-46kV
1.75"	46kV-69kV
2.5"	69kV-230kV
3.0"	230kV-345kV
3.5"	345kV-500kV

Fig. 2-3A: LP Application

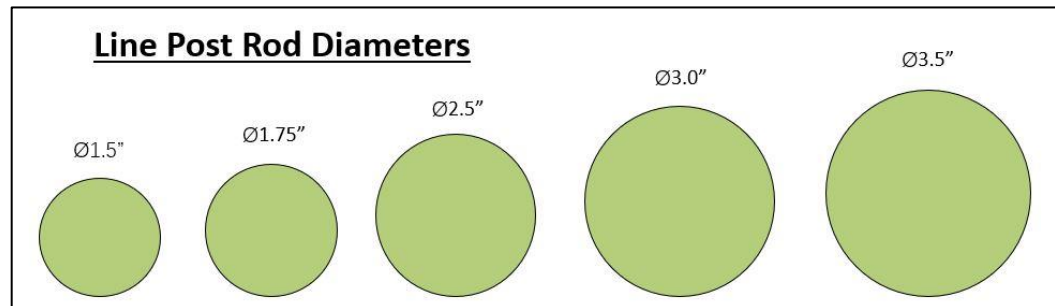


Fig. 2-3B: Common Line Post Rod Diameters (Not to Scale)

Facts & Comments:

- Primarily Cantilever Loading – Complex
- SCL – Specified Cantilever Load [Ultimate Cantilever Load]
- MDCL – Maximum Design Cantilever Load [Working Cantilever Load] – Typically 50% of SCL by standard, but some may choose to use 40% of SCL.
- SCL Ratings are limited by section length [The longer the post, the weaker it becomes]
- Standard E-Glass is commonly used, as brittle fracture has not been an issue for line post applications

2) Application of Rubber

As previously defined, the following manufacturing processes to apply rubber to the core rod assume the use of Silicone HTV Rubber (most common polymer insulator design).

2A) Housing – Sheath = rubber applied to the core rod

There are several methods by which the rubber housing could be applied to the core rod. The objective of any process is to apply a concentric sheath OD onto the core rod. The minimum thickness of the sheath must be $\geq 3\text{mm}$ (as defined by standards). Second to the minimum thickness is Bonding to the Core or adhesion of the rubber to the core rod. This is part of most manufacturing processes, but there are designs where the housing may be molded separate of the core and added to the core during a later process.

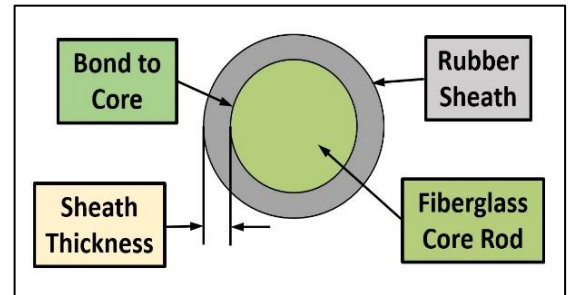


Fig. 2-4: Sheath Application

Bonding the rubber to the core during the application of the rubber to the core is by far the most used process, for injection molding, extrusion, and compression molding.

2B) Shed Profiles = Dry Arc & Creepage / Leakage Distance

The weather sheds of a polymer drive the dimensional values of the Dry Arc and Creepage / Leakage Distances. The sheds may be molded along with the sheath, or they may be added to the sheath as a secondary operation. Both options will be further defined later in this paper.

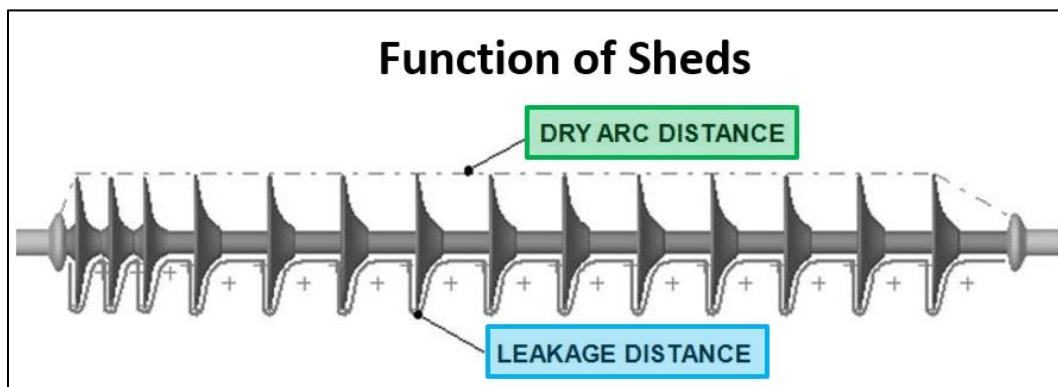


Fig. 2-5: Shed Function

Dry Arc Distance

- The distance across the shed profiles measuring the air gap from end fitting to end fitting
- The 2 critical sheds driving the dry arc distance are the first and last shed of the insulator.
- The # of sheds or spacing of those sheds have no impact on the dry arc distance.
- Impacts Dry Flashover & Withstand performance of the insulator.

Creepage / Leakage Distance

- The distance across the insulator, measuring the total surface area along each shed from end fitting to end fitting.
- Impacts Wet Flashover & Withstand performance of the insulator
- To ways to increase the leakage distance...
 1. Increase the qty of sheds
 2. Use alternating shed OD for higher leakage. (See shed profiles for details)
 3. Use Extra Large OD sheds for Maximum leakage

Shed Profiles

In order to meet the various leakage requirements, the supplier may choose to offer multiple shed profiles ranging from standard sheds to alternating sheds to Maximum OD sheds. This is again a detail left to the supplier to define and determine how they meet these differing leakage applications.

Facts on Shed Profiles:

- Putting too many sheds into a short section length insulator could have a counterproductive effect. More is not always better. Too many sheds may result in very short shed spacing, which may result in water bridging from shed tip to shed tip in wet conditions.
- Better to use Alternating sheds and increase length with leakage.
- The shed design / geometry is critical. Too thick and the design may not be cost effective. Too thin and the sheds could be easily punctured.
- It is critical to align the shed profile in a direction such that water will not sit on or pool on the shed. This would be most applicable in underhung applications, reversed connection applications.

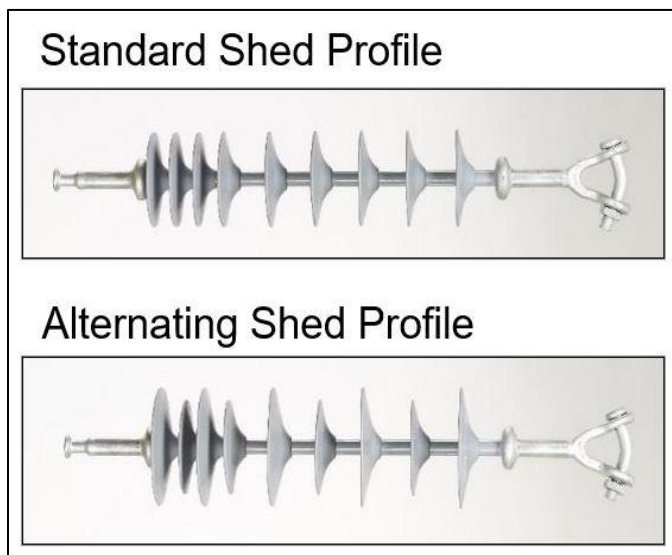


Fig. 2-6: Shed Profiles

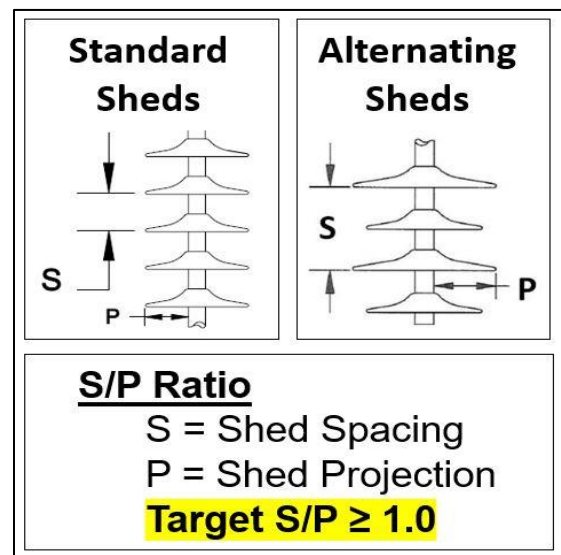


Fig. 2-7: S/P Ratio

S/P Ratio

S/P Ratio is the shed spacing divided by the shed projection, which is a good method to measure the proper proportion of leakage to section length of an insulator.

Shed Spacing = Distance from shed tip to shed tip on a Standard Shed Profile; and is the distance from large shed to large shed when applied to the Alternating Shed Pattern.

Shed Projection = Distance from shed tip to the surface of the sheath. In case of the Alternating shed pattern, the Projection would be the distance of the larger shed OD from the sheath.

S/P Ratio Target ≥ 1.0 – Ideal value

- Minimum value 0.8 is acceptable for less contaminated applications
- There is no Maximum, but research is still required on the effects of too few sheds or very large spacing.
- For High Contamination & EHV Applications – it is recommended to target an $S/P \geq 1.2$

Methods of applying rubber onto the core rod (most common MFG Technology – In no order)

- Injection Molding
- Compression Molding
- Extruded – Shed Assembly Design

Option # 1 - Injection Molding:

Injection molding is completed using a molding press and molding tools, typically referred to as a “Mold Cavity”. The press heats the raw rubber to a temperature at which it is viscous enough to be injected into the mold cavity via injection ports in the tooling. Conversely, the opposite end of the cavity has a vacuum port to pull the rubber, to assist in filling the entire mold cavity with rubber. Once full, the press continues to maintain temperature of the raw rubber until it cures into its final shape.

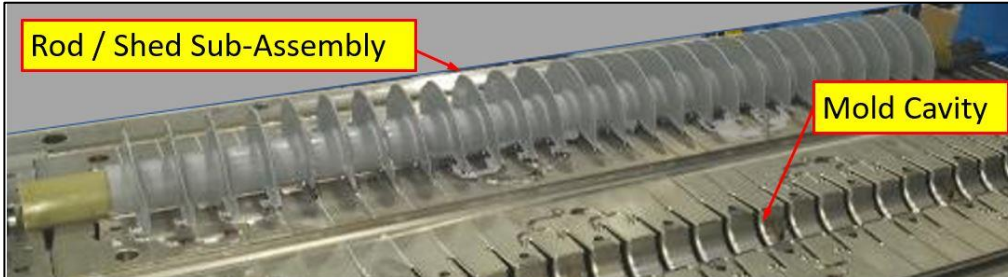


Fig. 2-8: Injection Molding Tooling

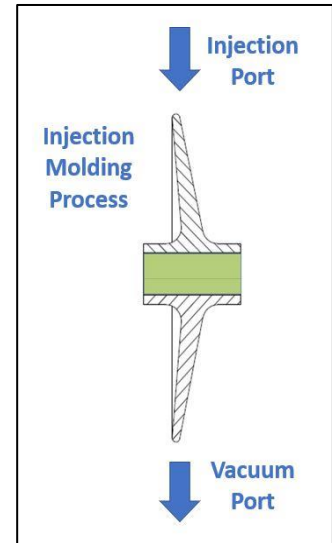


Fig. 2-9: Injection Process

There are two methods by which polymer insulators are manufactured using injection molding

- 1) **Molding rod / shed sub-assemblies**— rod and rubber sub-assembly, without end fittings. The molding press injects and bonds rubber onto the core rod, outputting rod/shed sub-assemblies (as shown in the Fig. x above). When molding a rod / shed sub-assembly, the tooling shuts-off onto the core rod, leaving behind bare rod where the end fitting will be attached at a later operation.
 - A benefit of molding a rod / shed sub-assembly is that any combination of end fittings can be attached onto the rod / shed to make a variety of different insulator designs (all having the same dry arc and leakage).
 - Maintaining a consistent mold temperature during injection and curing is critical to any molding process. It is much easier to control the temperature of the press when injecting onto the core rod (no end fittings)
- 2) **Mold-over the end fitting** – for this process, the end fittings are attached onto the core rod prior to going into the molding press. The rubber is injected onto both the rod and end fittings in one process.
 - Once the end fittings are attached, the insulator design is fixed and cannot change.
 - Heat is critical to proper curing and bonding of the rubber. The end fittings are a heat sink, causing inconsistent temperatures within the mold.

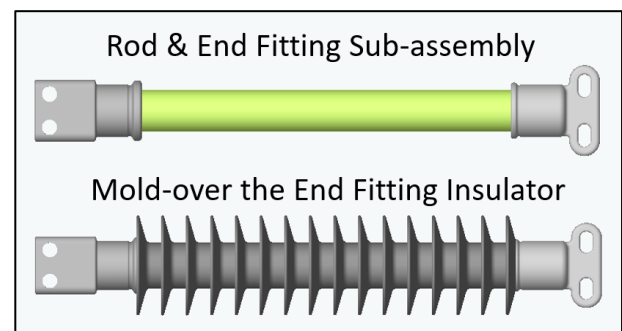


Fig. 2-10: Mold-over process

Additional Information pertaining to Injection Molding Polymer Insulators

- In order to assist bonding of rubber, the core rod (and end fittings on the mold-over design) are primed and pre-heated. This assures that the rubber properly bonds to the core (& EF), in the shortest injection cycle.
- Bonding is very critical to performance of the injection molded insulator. Poor bonding can lead to electrical performance issues in service. Best to have no voids or inclusions between the rod and rubber.
- The leakage and dry arc distances are defined by the tooling, which can only produce a specific shed profile. The outputs of that tool (shed profile) are fixed and can only be manufactured in a design defined increment, typically by shed segments.
- For each additional shed pattern required, a new tool or cavity inserts must be created, which also then requires change over down time to swap tools to produce different designs.

Benefits & Limitations of Injection Molding

Benefits [Pros]

- High Volume Production – Lower Costs
- Ideal to be molded to set schedule
- Standard / Catalog Designs / Length / Leakage
- Rod / Shed Sub-assemblies – various end fitting options that can be added after molding.
- Ideal process to duplicate, with multiple presses that can have interchangeable tooling.
- Great for lower voltage – single shot production.

Limitations (Cons)

- Not ideal process for low volume production
- Tooling Change = Down Time = Lost production time
- Not Flexible for custom length / leakage
- Potential for non-concentricity in the rod / sheath.
- Molding onto rod and metal (Mold-over process) tends to increase scrap due to bonding onto 2 different materials.
- Longer lengths require jump molding = inefficiency

Option #2 - Compression Molding:

Compression molding also uses a molding press, which has tooling / cavities that form the final shape of the insulator, but this press does not inject the rubber. In a compression mold, raw (uncured) rubber is applied onto the core rod, and then that rubber is compressed into the cavity, filling the cavity and curing the rubber during a heat cycle.

When molding a polymer insulator, the rubber is applied onto the core rod, typically in some form of extrusion, and then compressed in the mold. The raw rubber may be a very large sheath OD going into the press (Before in Fig. 2-11), then after compression and curing, the sheath would be a smaller OD, final sheath OD (After in Fig. 2-11).

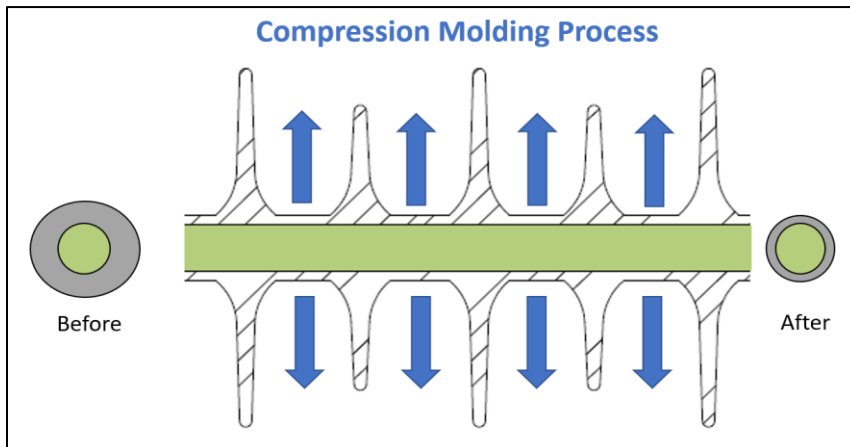


Fig. 2-11: Compression Molding of a Polymer Insulator



Fig. 2-12: Compression Mold Shed

Compression Molding is also very commonly used to mold the sheds used on an Extruded / Modular Assembly insulator (See Fig. 2-12). In this process, a ring of rubber is placed into a mold cavity, compressed to fill the cavity, and cured by applying a heat cycle.

Benefits & Limitations of Compression Molding

Benefits [Pros]

- High Volume Production – Lower Costs
- Shorter Molding Cycles = Faster thru put.
- Standard / Catalog Designs / Length / Leakage
- Rod / Shed Sub-assemblies – various end fitting options that can be added after molding.
- Lower cost Presses and Tooling compared to investments into Injection Molded Equipment.

Limitations (Cons)

- Tooling driven production / not ideal for low volume.
- Tooling Change = Down Time = Lost production time
- Not Flexible for length / leakage
- Potential for non-concentricity in the rod / sheath. Less control over concentricity, requires thicker sheath to compensate. Cross section may look egg shaped, like shown in Fig. 2-13

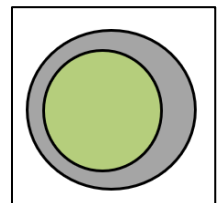


Fig. 2-13 - Concentricity

Option #3: Extruded Manufacturing Process:

This process is very different from the first 2 molding processes. The rubber is extruded onto the core rod, using 4 injection ports from 4 equally spaced quadrants. This assures that the rod is concentric to the OD of the sheath that is being formed. This is a unique benefit to the extrusion process, unlike the previous molding processes where unbalanced injection and uncontrolled rod position may cause rod bowing, and that egg shaped concentricity shown in Fig. 2-13. The other main difference in the extruded process is the cure time and curing cycle. The raw silicone formulation used in extrusion is designed to cure immediately upon extrusion onto the core rod.

The rod is primed and pre-heated just like in the molding operations, but the silicone is cured into its finished state in-line, without any delayed fill time (to fill the cavity with rubber) and without a hold time in the press for the rubber to cure once the cavity is filled. The main difference between an extrudable silicone and molding silicone is the curing agents, specifically the time delay mechanism for onset of curing.

The Extruded manufacturing process involves 5 steps to make a polymer insulator, 4 of which we will cover in this section. Fig. 2-15 illustrates the process, step by step.

- 1) Extrusion onto the core rod – this process is completed in-line and is usually done on 20 FT or longer sticks of fiberglass rod.
- 2) Cut to Length & Rod End Preparation – The sheathed rod is then cut to the specific length of the insulator, and the ends are “De-sleaved” and sanded to remove any residual silicone rubber from the rod ends.
- 3) Shed Assembly

Sheds – The sheds are molded off-line of the assembly and stocked as components.

Shed Prep. - Prior to being assembled, each shed is injected with a silicone based cross link paste (not a glue) to promote bonding with the sheath.

Rod Prep/ - The entire sheathed rod passes through a cross link paste process, which also acts as a lubricant to help slide the sheds on during assembly.

Shed Assembly – The cross link coated sheds are placed strategically (based on shed profile and leakage) into shed holders, which hold the sheds in place while the rod is pushed through them all to assemble the final shed profile.

The rod / shed sub-assembly is then cleaned to remove excess paste and staged on carts awaiting an oven cycle.

- 4) Oven Cycle / Bonding of Sheds to Sheath – the fully loaded carts are placed into a large oven, and the entire lot of products are vulcanized, where the cross-link paste promotes a chemical reaction, essentially resulting in two individual silicone bodies (sheath and sheds) to become one material. Prior to the oven cycle, the sheds can be moved and adjusted, but after the oven cycle, they are fixed in place. The bond between sheath and shed is stronger than the tear strength of the silicone rubber.

After the oven cycle is complete, sub-assemblies are removed from the oven to cool, then prepared for end fitting attachment. More to follow on that in next section.

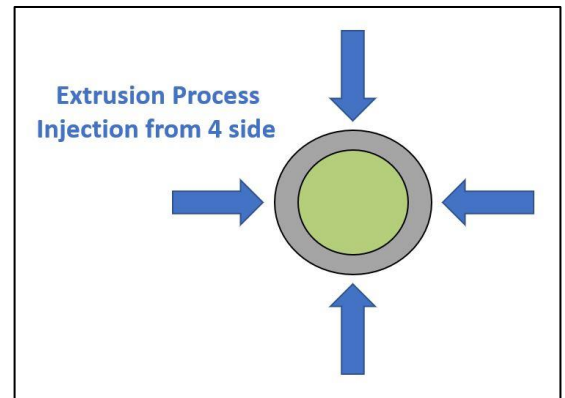


Fig. 2-14: Extrusion Process

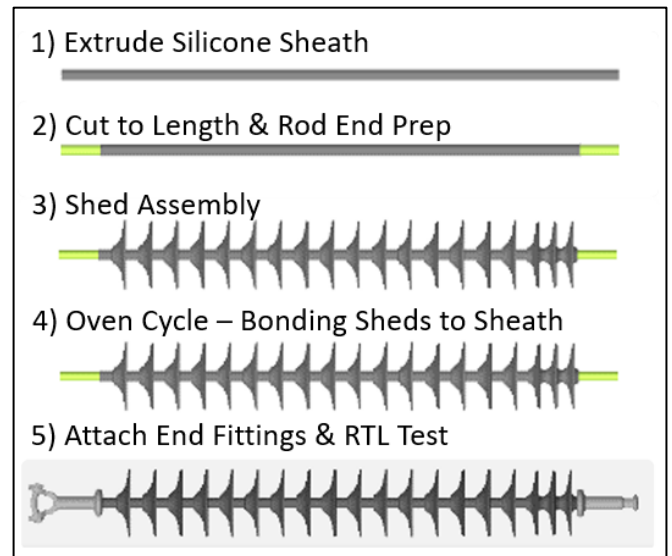


Fig. 2-15: Extruded Assembly Process

Benefits & Limitations of the Extruded Assembly Process

Benefits [Pros]

- Used to produce standard and custom designs
- Variable Length and Leakage options, ideal for Engineered Solutions and EHV Length Insulators.
- Made to Order – stocking of components, not finished insulators.
- Just as efficient to make 10 as it is 1,000.
- Quick change from one design to another, including switching core rod diameters and length.

Limitations (Cons)

- Can be labor intensive = higher costs
- Can be subject to production bottle necks
- Reliant on proper component planning and stocking
- More catalog SKU

Facts & Comments:

- No matter the manufacturing process, when made correctly with good materials, the resulting insulators (when designed with equal dry arc distance and leakage) should perform the same in service.
- All three processes are capable to manufacture both suspension and line post insulators.
- When evaluating any of the processes defined above, it would be best to focus on the process, how repeatable that process is, and how the supplier evaluates quality during the process.
- Ideally, the supplier has a system of toll gates to catch and isolate errors in production to prevent those defects from potentially reaching the field. A good evaluation of process would include checking how the supplier catches errors, in what step of the manufacturing process, and what actions they take to correct the error. Mistakes happen, it is how they are managed and prevented that are differentiating factors.
- For a supplier to have the ultimate service capability, they would have a good combination of injection molding for low voltage / high volume production, and the extruded shed assembly for the higher voltage / engineered solutions required to support our ever-changing demands of our customers.

3) Attachment of End Fittings to Core Rod

The most common process used to attach the end fittings to the rod / shed sub-assembly is the compression process, known in the industry as the Crimp Process. We will not go into detail on the epoxy potting process, as this has become virtually obsolete, or should be made obsolete.

Equipment: in order to crimp an end fitting, the supplier will select a crimp press, of which there are many to choose from. A crimp press can be as simple as a two-piece die, or it may combine the use of 4, 6, or 8 compression die sets. The 8-segment crimp die is most popular.

While the crimp press may be an off the shelf product available to one and all suppliers, the system of compression, controls, die set design, and holding fixtures are all defined by each manufacturer.

The programming and system controls are especially critical to the crimp process, and this should be something the supplier is prepared to show case during a customer visit / quality audit.

The original crimp presses used for the first crimped end fittings were not as sophisticated as the presses available today. In many machines, the programing controllers are built into the press, with easy to program pressure settings. The machines are better prepared to be automated and fixed with measuring tools and counters. Some presses come with self-lubricating die sets, which cut back on maintenance and down time.

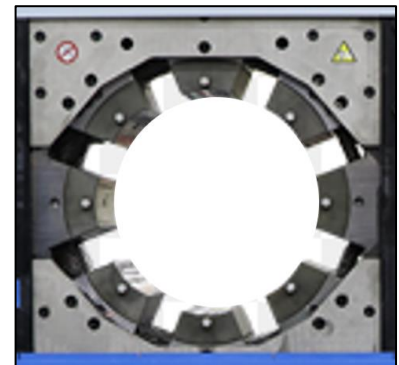


Fig. 2-16: Crimp Press

Tooling: The crimp dies are a critical design features that each supplier must develop and design, regardless of what crimp press they use.

Design Factors:

- Round Dies vs Flat Dies – proprietary to each supplier based on their testing and experience
- Crimp Forces – ideal force to get maximum tensile strength, without cracking the core rod.
- Crimp Zone & Crimp Length – is the crimp complete in 1 crimp process, or does the supplier crimp 2, 3, or 4 times using shorter dies and fixturing to index the insulator through the multi-crimp process.
- The “D” dimension is determined by the end fitting / core rod diameter being crimped.
- The “L” dimension is defined by the supplier crimp zone, number of crimps, etc.

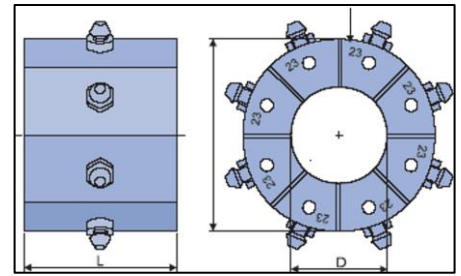


Fig. 2-17: Crimp Dies

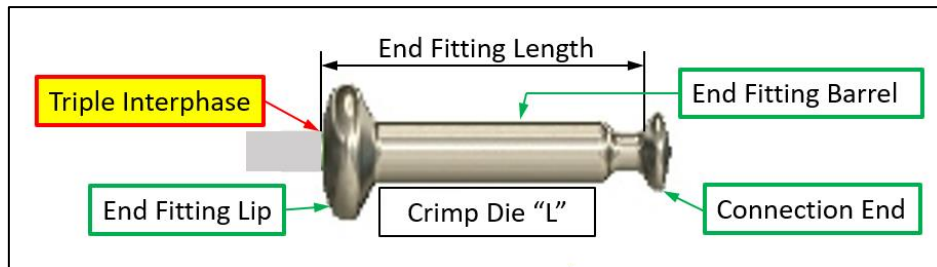


Fig. 2-18: Crimped End Fitting

Facts and Comments:

- The crimp process should be accompanied by a good quality process to validate and verify the crimp performance, which would include some form of 3 Sigma Control of tensile performance.
- The supplier should be prepared to go into detail on how the crimp process is defined and maintained.
- Acoustical Emission Recording during the crimp. While this was a process that was required early on for first generation crimping, it has since been shown that it is better to understand what causes rod to crack, and at what crimp forces, and those elements should be designed out of the process to prevent them from occurring.

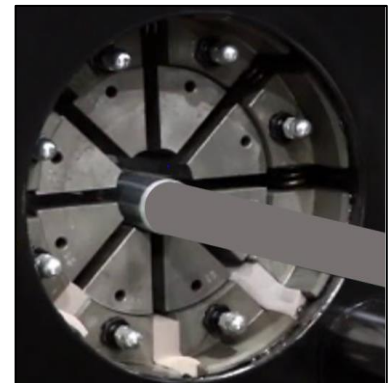


Fig. 2-19: Crimp Process

4) Method of Sealing at the Triple Interphase

History has shown that the #1 cause of issue on early generation polymer insulator was due to poor or no seal. Over time, the seal has become a differentiating feature by which many insulators are evaluated and approved. Today, there are several potential sealing options, Compression Sealing, RTV Sealing, and Mold-Over the end fitting seal.

Compression Sealing: the sheath of the insulator is compressed into the end fitting, creating a mechanical seal on each insulator.

- The compression process should be automated as part of the crimp process to eliminate the impact of human error.
- Ideally, the seal would have multiple layers, with some redundant layers in case one layer is compromised.

RTV Sealing: for this process, the end or the sheath is pushed into the end fitting, manually, and then finished with an RTV Layer.

- The RTV layer is in some cases the only seal, and while RTV is a good silicone material, it does not have the longevity of the HTV Silicone. The RTV is usually the first silicone material to show signs of aging.
- The RTV layer may also go by the name Silgel, which is a 2-part mixed silicone gel that fills the void between end fitting and core rod.

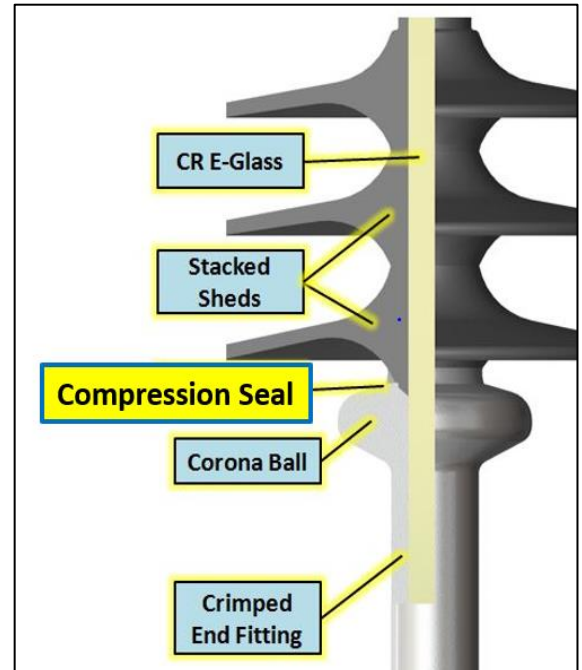


Fig. 2-20: Compression Seal



Fig. 2-21: Mold-over line post

Mold-over the end fitting Seal: this process requires including the end fittings in the molding process, which can cause bonding issues.

- This is a great seal on paper, but less favorable with respect to production.
- Bonding to the end fitting can cause high scrap rates, and may have some issues passing standard industry tests. (Keep in mind that while the metal is covered in rubber, electricity will find the weak link and exploit it, puncturing to the end fitting through the rubber vs going around it as proposed on paper.
- Once the insulator is molded, the end fittings are fixed and cannot be changed. This can impact the supplier's flexibility in service and forecasting production.



Fig. 2-22: Mold-over Suspension

Sealing Systems in Review: the selection of the right process for sealing may be the most important design detail each supplier must define. There are no standards that suggest how to seal the insulators, but the standards do provide very clear steps by which to test and evaluate the seal, along with all the other manufacturing processes.

Facts & Comments

- First and foremost, the customer should focus on the performance and history of the sealing system. What works for one may not be the right process for another.
- Go and See – Witness the process, ask questions how it works, how operators might impact the seal, and what quality steps are taken to assure that the seal is good.

5) Design & Application of Corona Rings

Corona Rings are the final complex piece of the Polymer Insulator. Like 90% of the polymer design, very little is defined or required in standards, and like all other variables, the supplier is left to making the decision on what to use and when (what voltage). Corona rings are a vital part of long-term polymer performance, so it is critical to have the right design applied to the insulator in the right location for optimized protection. The Size and Shape of the corona ring is a major contributor to the optimized performance. Knowing when to use a corona ring and what size to use is very important to the customer. Best if this recommendation is supported by Testing and or an E-Field Model Report.

Corona Ring Design:

Shape: Fully Enclosed Ring – Open C Shape Ring

- For DC, a fully enclosed ring may be required.
- Open C Shape – Ideal for AC performance, and can be applied to the line after installation (energized if need be).

TD: Torus Diameter of Corona Ring

- Thickness of the Corona Ring Body
- Too Small = not enough grading
- Too Large = Not material effective
- Tubular Torus – DC / Corona Shield
- Torus – Open C-Shape Geometry

OD: Outside Diameter of Corona Ring

- OD determined by voltage
- Too Small = not enough protection
- Too Large = may result in proper protection

Common Line End Corona Rings:

6" – 8" Corona Ring – 115kV – 230kV AC

11" – 12" Corona Ring – 345kV / 400kV AC

15"-17" Corona Ring – 500kV / 765kV AC

Common Applications:

A Corona Ring is almost always applied at the line end of the insulator, but for some applications they are applied to both line and tower ends

Line End – 115kV to 230kV

Line & Tower Ends – 345kV to 765kV

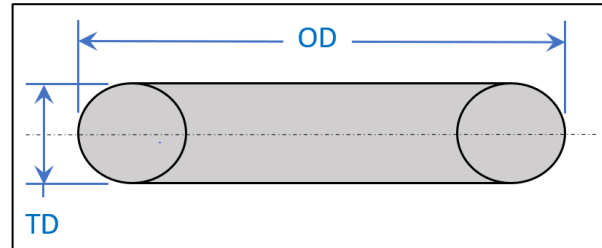


Fig. 2-23: Corona Ring Geometry



Fig 2-24: Corona Rings

Recommended Corona Ring Applications								
	115kV	138kV	161kV	230kV	345kV	500kV	765kV	
Catalog Ref.	X	X	A	A	B	G	V	H
Line End	*	*	8"	8"	12"	12"	17"	17"
Tower End	—	—	—	—	—	8"	8"	12"
Stacked Shed	SS	SS	SS	SS	SS / EHV	EHV	EHV	UHV

* 8" Corona Ring available if required by customer or to satisfy modeling

Fig 2-25: Corona Ring Application Table



Fig 2-26: Corona Shield

Corona Shields:

Corona rings are specific to the insulator, and should be considered part of the insulator (as they the inclusion of the corona ring it will impact Electrical Performance).

Corona Shields are part of an assembly, which includes the insulator(s) and hardware. Shields may be supplied to protect (shield) ceramic disc insulators, or they may be needed to protect the conductor hardware. In both cases, the shield will impact the strike distance of the assembly, and may be required to fit within a customer's specified Hot Box or area the shield must fit within for phase clearances.

Conclusion:

Not All Polymer Insulators are the Same, and none are made the same way. Standards define some aspects of a polymer, but mostly on what tests it must pass to be approved. The customer faces many challenges when approving a polymer supplier, but as stated many times in this paper, the customer should focus on the performance of the polymer insulators, not so much how they are manufactured. Beyond the performance of the insulator, the customer absolutely must go see the factory and audit the quality systems in place to assure consistent manufacturing of product. It is not easy, but if done correctly, this will help qualify worthy suppliers.

Appendix 2A: Smart Fit Corona Rings

The Smart Fit Corona Ring is designed to attach onto the corona ball feature of the end fitting. The Ring has a 2-piece keeper system that allows for the corona ring to be put onto the insulator before or after installation in service. The geometry of the keeper matches the geometry of the end fitting corona ball, developed in such a way that it would take more effort to apply the corona ring incorrectly vs applying it the way it was designed and validated to fit.



The corona ring has a 2-piece keeper system, that when loosened, opens to fit onto the corona ball feature of the end fitting. After the corona ring is aligned correctly, the keepers are tightened, and the corona ring is where it needs to be to properly protect the insulator.

