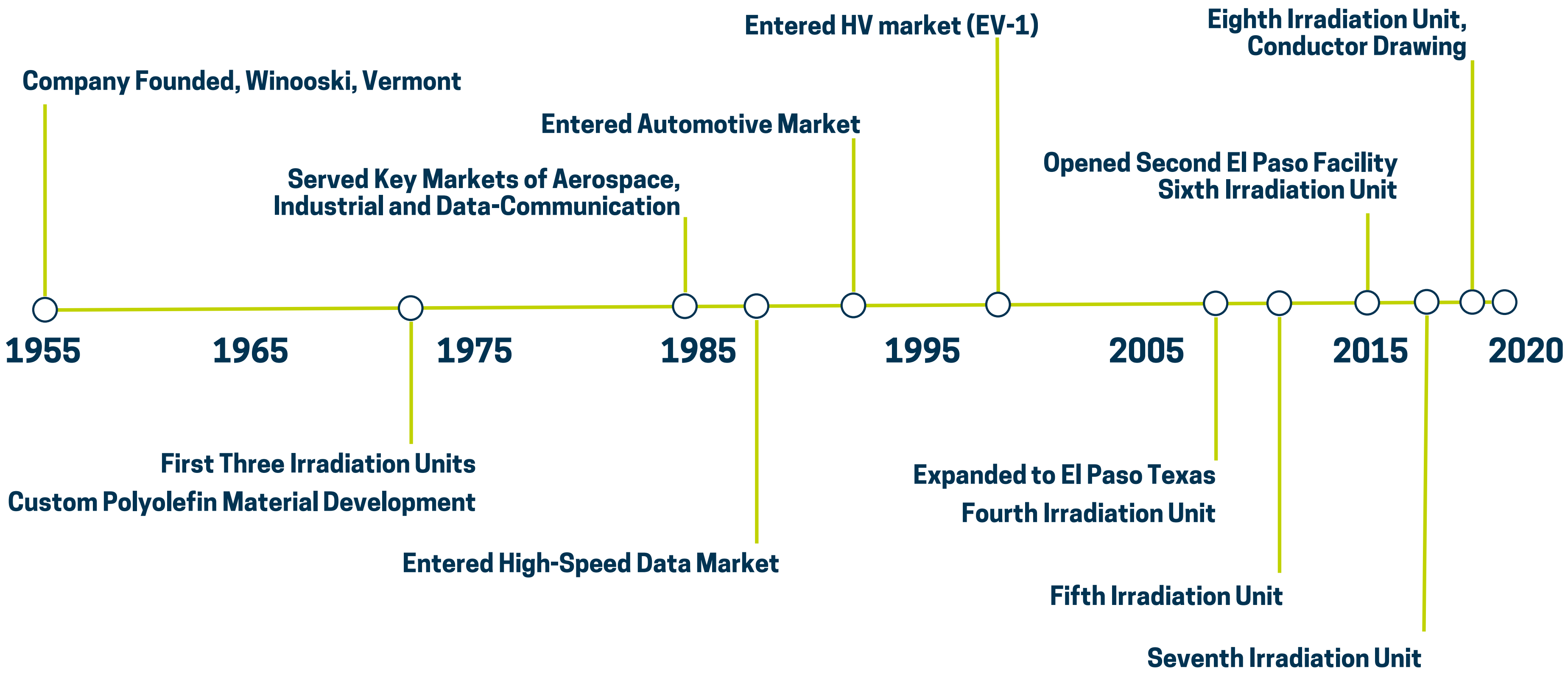
CHAMPLAIN CABLE

ADVANCEMENTS IN AUTOMOTIVE XLPO HIGH-VOLTAGE CABLE DESIGN

Industrial & Mining | Automotive, Commercial Vehicle, e-Mobility | Military & Data | Rail Transit

CHAMPLAIN CABLE

A world leader in irradiation crosslinking technology in the wire and cable industry



Champlain Cable holds multiple US patents for material and processing technologies

MATERIAL SCIENCE

- Today's polymer technology is far more advanced than years past

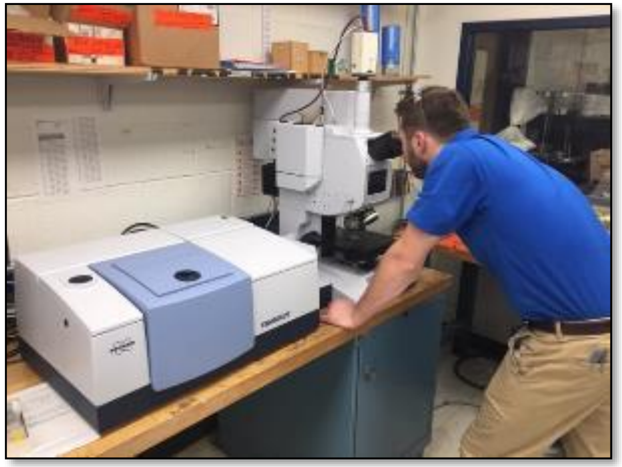
- Advancements include the chemistry of the materials themselves, and also the analytical tools available to research, blend and create new materials

- Flexural Modulus: A measure of a materials resistance to bending when force is applied
  - Cutting edge advancements in lowering flexural modulus properties of polymers allow for XLPO materials to be more flexible than ever before

MATERIAL SCIENCE

- Rheology: The study of material flow under applied stress
- Rheology optimization allows for improvements in the extrusion process resulting in tighter diameter tolerance and a smoother surface for connector sealing

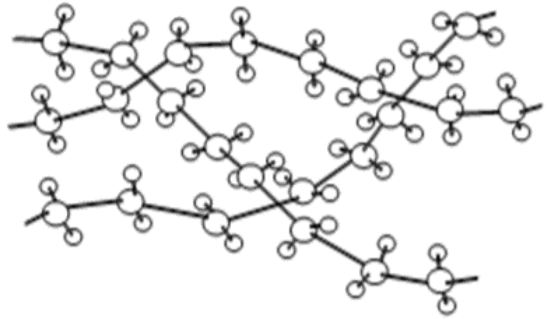
- Blending Facilitators: Improve dispersion and homogenization of ingredients resulting in a more consistent polymer
- This results in better overall, and consistent cable performance for properties such as flame resistance and thermal stability



Champlain's state-of-the-art Bruker Hyperion 3000 FTIR microscope

MATERIAL SCIENCE

- **Compatibilizers:** Allow the mixing of polymers with different properties to take advantage of each polymer's strength
- Compatibilizers help to create a super-blend of polymers with properties that one polymer alone cannot perform



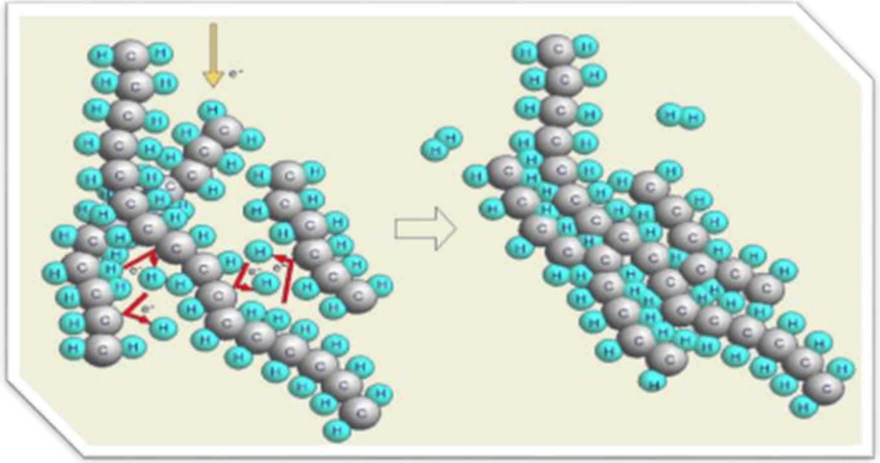
- **New Polymer Technologies:** Raw material suppliers are constantly improving polymers which can improve cable performance in areas such as, flexibility, oil resistance, volume resistivity, water resistance, and other properties

Advances in polymer science have been a catalyst for the development of some of the highest performing XLPO's to-date.

IRRADIATION CROSSLINKING TECHNOLOGY

- **Cross linking:** The process of permanently linking polymer chains together with carbon to carbon bonds
- The polymer changes from a thermoplastic (which can melt) to a thermoset (which will not melt)

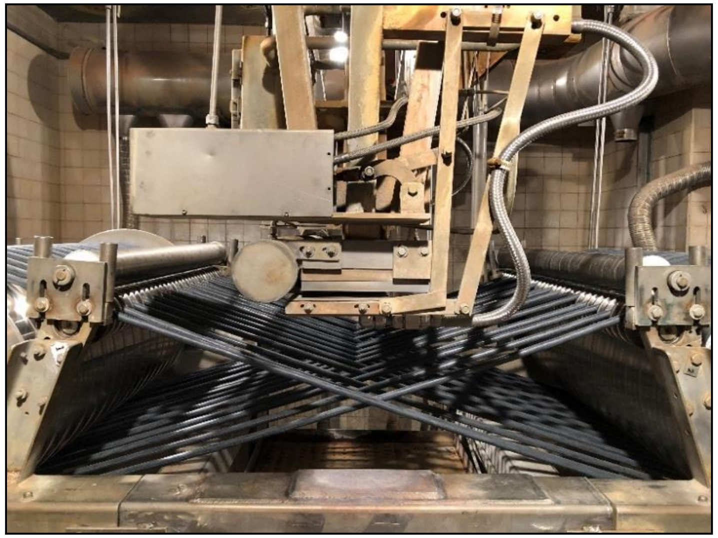
- Many performance properties are enhanced:
  - Oil and fluid resistance
  - Heat resistance
  - Abrasion performance
  - Compressive force resistance
  - Plus other attributes…



IRRADIATION CROSSLINKING TECHNOLOGY

- **Irradiation:** A method of cross-linking utilizing a stream of high-energy electrons to create these carbon-to-carbon bonds which link the polymer chains together
- Irradiation is a very controlled process allowing the highest performance possible

- Other cross-linking methods, such as chemical or silane / moisture cure, are not as well controlled and have polymer and thermal limitations compared with irradiation cross-linking



Cable under an Irradiation unit

IRRADIATION CROSSLINKING TECHNOLOGY

- Irradiation cross-linking allows cost effective modification of a wide array of polymers to significantly improve their performance
- This allows HV cables to be used in harsh environments such as temperature extremes, fluids, mechanical stress and other challenging conditions
- Advanced polymer formulation can also yield products with additional features such as:
  - Improved flexibility
  - Higher voltage withstand allowing thinner walls and smaller diameters
  - Longer life
  - Processing advantages, and other benefits.

Image courtesy of Schleuniger Corp.

Irradiated XLPO's are the high-voltage material of choice by many Tiers and OEM's

EXRAD®

KEY PERFORMANCE CONSIDERATION

COMPRESSION SET / DEFORMATION

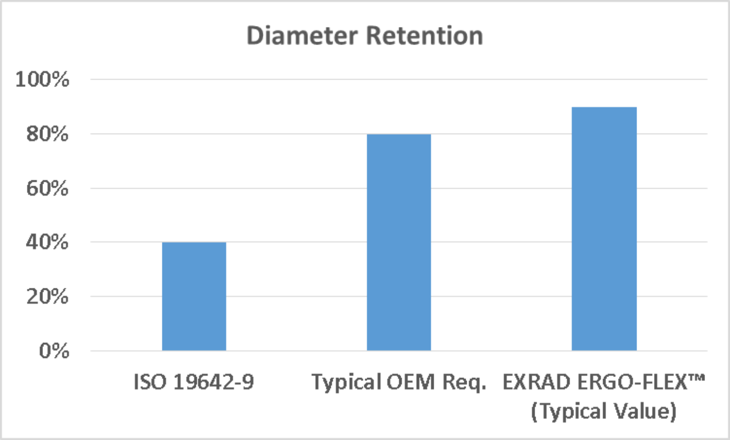
- The tendency of cable insulations to permanently deform due to pressure at elevated temperatures
- This deformation can cause failure at a connector seal, allowing ingress of water which can cause electrical failure
- Resistance to this deformation is a key cable attribute for proper long-term connector sealing and performance
- Connector suppliers are also modifying their connectors to better manage deformation

Deformation caused by connector pressure at elevated temperatures

KEY PERFORMANCE CONSIDERATION

COMPESSION SET / ORIGINAL DIAMETER RETENTION

- ISO-19642-9 outlines a minimum diameter retention requirement of 40%
- Many OEM's have established their own more stringent requirements in order to ensure integrity of the cable / connector interface
- The requirement is optional per the ISO-19642 standard, but typically considered an industry best-practice



Diameter retention is a key consideration when selecting HV power cables.

KEY PERFORMANCE CONSIDERATION

THERMAL ROBUSTNESS

- HEV engine compartments typically have high nominal temperatures and components must perform for thousands of hours
- Even in EV systems with no ICE, high current will heat up cables due to temperature rise
- Thermal performance is even more critical when both environmental temperature and current are affecting the cable, and when cables are routed in close proximity with limited air flow

EXRAD HV cables in commercial HEV system

KEY PERFORMANCE CONSIDERATION

THERMAL ROBUSTNESS

- HV cables must be designed to withstand elevated temperatures for extended periods of time
- ISO 19642 cable standards define short- and long-term heat aging requirements
- Cables should withstand thermal excursions beyond their rated temperature class to ensure they don't fail before circuit breakers / fuses can activate

3000hr 150°C Heat Aging:
Left: 150°C chemically crosslinked XLPO
Right: 150°C Irradiated EXRAD ERGO-FLEX XLPO

The thermal requirements of EV/HEV cable systems require careful review.

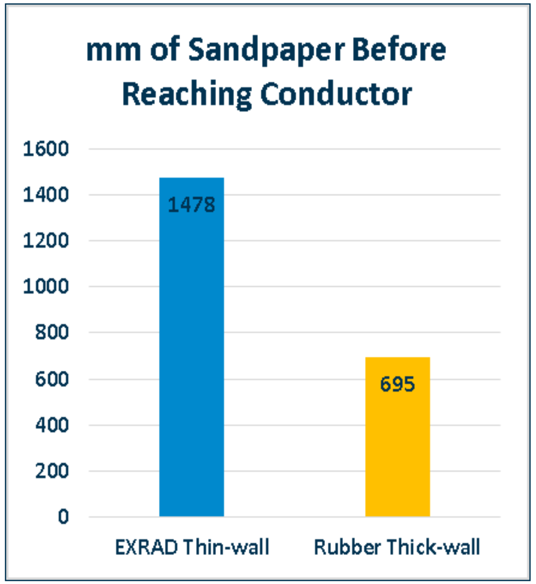
KEY PERFORMANCE CONSIDERATION

MECHANICAL STRENGTH

- Mechanical strength such as abrasion and pinch resistance determines the life of a cable when in contact with these forces
- Cables with poor abrasion resistance are susceptible to potential failures:
  - Thin spots in insulation are at risk of a high-voltage breach
  - Excessive forces can cause exposed conductor and risk electrical failure
- ISO-19642-5 requires an abrasion test for sizes 6.0mm and smaller. Larger sizes is at customer discretion.
- High-performing thin-wall XLPO cables often perform better than thick-wall rubber cables, saving space, weight and cost

KEY PERFORMANCE CONSIDERATION

ABRASION RESISTANCE

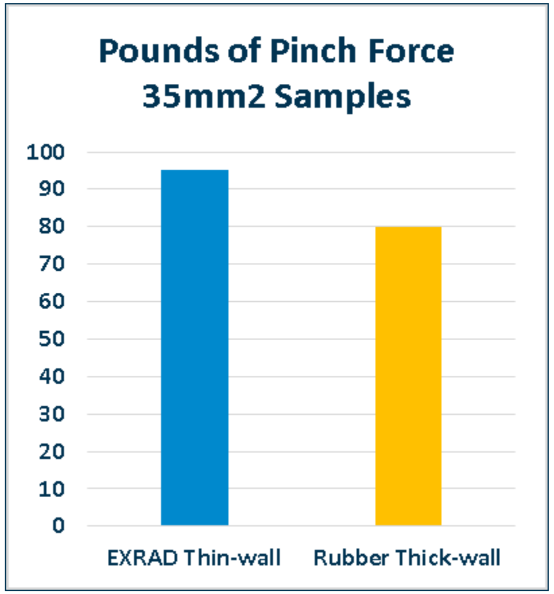


Over 2x better sandpaper resistance per ISO-19642 test procedure

Top: 35mm2 <u>thick</u>-wall rubber
Bottom: 35mm2 <u>thin</u>-wall EXRAD

KEY PERFORMANCE CONSIDERATION

PINCH RESISTANCE



95 pounds maxed out test apparatus
ISO-19642 test procedure

Cables after pinch force test.
Top: EXRAD thin-wall. Insulation intact (95lbs)
Bottom: Rubber thick-wall. Insulation severed (80lbs)

HV cables must be tough enough to withstand vibration and accidental stresses

KEY PERFORMANCE CONSIDERATION

FLUID AND CHEMICAL RESISTANCE

- Automotive fluids can have a degenerative effect on cable insulations
- The insulation can absorb/react to the fluid and cause a split in the insulation and an electrical short
- Fluid resistance at elevated temperatures is much more difficult than ambient temperatures
- Cables in EV's can be exposed to fluids including brake, power steering, transmission, washer, lubricants and others

ISO-6722-1 Oil Swell. Max allowable = 15%
Top: Chemically crosslinked EPDM. 95% Swell.
Bottom: Irradiated EXRAD XLPO. 9% swell.

KEY PERFORMANCE CONSIDERATION

FLUID AND CHEMICAL RESISTANCE

- There are critical differences between ISO specifications
- **ISO-19642:** 10-second fluid exposure followed by a 240hr bake cycle at rated temp and repeated 4 times
  - Simulates resistance at rated temperature, but very limited fluid exposure
- **ISO 6722:** 20hr immersion followed by a winding and voltage test. % swell is also measured.
  - Simulates repeated / continuous exposure

Potential fluid exposure is an important HV cable system design consideration.

KEY PERFORMANCE CONSIDERATION

ISO-19642-5 &-9 (HV) CONFORMANCE

- Cable standards for vehicles have advanced significantly over the past 20 years
- ISO-6722-1 was the primary global standard for many years, but did not cover shielded, multi-conductor, 1,000V, or aluminum conductors. Those cables were covered by other ISO standards or OEM standards.
- ISO-19642 is the latest-generation standard for vehicle cables, and encompasses a broad array of cable types
- There are 10 sub-sections of the 19642 standard
  - 19642-5: single core HV copper cables up to 1,000VAC / 1,500VDC
  - 19642-9: screened and multi-core HV copper cables up to 1,000VAC / 1,500VDC

KEY PERFORMANCE CONSIDERATION

ISO-19642-5 &-9 (HV) CONFORMANCE

- **ISO 19642 added new test procedures and performance values to address evolving HV market needs**
  - **Diameter Retention Under Pressure:** To improve connector sealing
  - **Cable Flexibility:** To quantify relative flexibility of a cable
  - **Screening Effectiveness:** To quantify and define shielding performance
  - **Abrasion Testing:** A required test for 6.0mm and smaller
  - **High-Voltage:** Increased voltage from 600VAC to 1,000VAC and added 1,500VDC
  - **Shielded Diameter Tolerances:** To improve consistency across suppliers and connector interoperability

ISO 19642 is the latest vehicle standard and is more robust than prior standards.

WHITE PAPERS

- **Champlain has published a number of white papers to help educate end-users on technological topics**
  - Irradiation Cross-Linking
  - Automotive Ethernet – Cable Design
  - Automotive Ethernet – Heat Aging
  - Irradiated EXRAD vs. Silicone rubber
  - Irradiated EXRAD vs. EPDM rubber
  - Evolution of Vehicle High-Voltage Standards
  - Thin-wall Irradiated EXRAD vs. Thick-wall Silicone

https://www.champcable.com/resources/#whitepapers

CHAMPLAIN

Evolution of ISO High Voltage Copper Cable Standards for Vehicles

Cable standards for vehicles have evolved significantly over time. For decades standards were typically regional in nature; SAE for North America, JASO for Asia and ISO-6722 and LV-112 for Europe. There were both similarities and differences of varying extremity between these standards.

In the early 2000's, ISO 6722 began emerging as the global standard for unscreened single-core copper vehicle cables, although other regional and OEM standards existed and continue to be used today.

In 2001, ISO 14572 was introduced to address single and multi core copper cables, with screened and unscreened options. 14572 referenced 6722's single-core standards. In 2011, ISO 6722-1 was published which was a revision of ISO-6722:2006. In 2013, ISO 6722-2 was published to address aluminum conductors in unshielded, single-core cables.

Still, emerging market technologies needed a single, more comprehensive standard. Higher voltages were being used in EV/HEV technologies, cable geometry and insulation material performance was affecting connector sealing, and cable flexibility continued to become more critical for both application demands and human ergonomics.

In 2019, ISO 19642 was published to expand upon and consolidate 6722-1, 6722-2 and 14572 into one standard. 19642 is divided in to 10 sections addressing terminology, test methods, and dimensions; plus it breaks out cable groups by low vs. high voltage, copper vs. aluminum, single vs. multi-core, and screened vs. un-screened. 19642 was written to allow for future expansion as technologies emerge.

With regard to high-voltage copper cables (sections -5 and -9 of 19642), the consolidation resulted in mostly minor modifications to the original standards. However there are eight somewhat pronounced differences affecting HV cables that this document will review.

KEY TAKEAWAYS

- **Polymer technologies have improved dramatically over the past 10+ years**
- **Irradiation cross-linking + material science yields very high-performing XLPO cables**
- **Todays technologies allow for a more 'complete' XLPO cable, combining high-flexibility, thermal robustness, toughness, fluid resistance, process-ability, and meeting the latest vehicle standards**
- **Irradiated XLPO's are becoming the material of choice by many Tiers and OEM's for HV cable long term reliability and safety**