Master's thesis

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Material substitution for MV cable accessories

– substitution process for cold shrink joint

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Master’s Thesis | Abstract

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Material substitution for MV cable accessories

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This Master's thesis was commissioned by Ensto Finland Oy, a company that designs and offers electrical solutions for electricity distribution. The aim of the Master´s thesis was to determine the possibility of using the same liquid silicone rubber material in the manufacturing of underground cold shrink terminations and joints. The subject of this thesis became even more crucial due to recent global events that have caused problems in the availability of raw materials.

The topic was approached using both basic research and experimental research methods. With the quantitative research, deductive reasoning was utilized to draw conclusion based on the results and findings. When considering material substitution all various factors such as the technical performance, the economic advantages and the environmental and legislative aspects were taken into account.

The results indicated that it is possible to use the material in both cold shrink joints and terminations. In order the maintain and control quality, the documented framework - control plan, that outlines the steps and measures to be implemented for the material substitution process should be developed.

Keywords:

Cold shrink termination, Cold shrink joint, liquid silicone rubber, material substitution, liquid injection molding

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Minna Baarman

Keskijännitemaakaapelivarusteiden materiaalin vaihto

- kylmäkutistejatkojen materiaalinvaihto prosessi

Tämä maisterin tutkielma tehtiin Ensto Finland Oy:lle, yritykselle joka suunnittelee ja tarjoaa sähköalan ratkaisuja sähkön jakeluun. Tutkielman tavoitteena oli selvittää mahdollisuus käyttää samaa nestemäistä silikonikumimateriaalia kylmäkutistepäätteiden ja –jatkosten valmistuksessa. Tutkielman aihe tuli entistä tärkeämmäksi viimeaikaisten maailmanlaajuisten tapahtumien vuoksi, jotka ovat aiheuttaneet ongelmia raaka-aineiden saatavuudessa.

Aiheeseen lähestyttiin sekä perus- että kokeellisen tutkimuksen menetelmin. Työssä käytettiin deduktiivista päättelyä ja stategiana oli kvantitatiivinen tutkimus. Materiaalin vaihdossa otettiin huomioon eri tekijät, kuten tekninen suorituskyky, taloudelliset edut sekä ympäristö- ja lainsäädännölliset näkökohdat. Tulokset osoittivat, että saman materiaalin käyttö jatkoissa ja päätteissä on mahdollista. Laadun ylläpitämiseksi ja valvomiseksi tulisi kehittää valvontasuunnitelma.

Asiasanat:

Kylmäkutistepääte, kylmäkutistejatko, nestemäinen silikoni, materiaalin vaihto, nesteruiskuvalu

Content

Appendices

Figures

Tables

List of abbreviations (or) symbols

ASTM	ASTM International, founded as the American Society for Testing and Materials
D4	Octamethyltetracyclosiloxane
D5	Decamethylpentacyclosiloxane
D6	Dodecamethylhexacyclosiloxane
FINAS	Finnish Accreditation Service
GWP	Global warming potential
IEC	International Electrotechnical Comission
HD	CENELEC Harmonization Document
LIM	Liquid injection molding
LSR	Liquid silicone rubber
Material 1	Insulating liquid silicone rubber
Material 2	Insulating liquid silicone rubber with tracking resistance
Material 1 LIM	Liquid injection molded sample of Material 1
Material 2 LIM	Liquid injection molded sample of Material 2
MV	Medium voltage
PBT	Persistent, Bio accumulative and Toxic
PDMS	Polydimethylsiloxane
Pt	Platinum
REACH	Registration, Evaluation, Authorization and Restriction of Chemicals

RPM	Rounds per minute
RTV	Room temperature vulcanization
SCIP	The substance of concern in articles as such or in complex objects, products
SVHC	Substances of very high concern
UV	Ultraviolet
VOSiC	Volatile organic silicon compounds
vPvB	Very Persistent, very Bio accumulative

1 Introduction

The subject of this Master's thesis was to determine whether it is possible to use the same liquid silicone rubber in both underground cold shrink cable accessories like terminations and joints. The Master´s thesis was commissioned by an international technology company and a family owned business that designs and offers electrical solutions for electricity distribution. The thesis examines the material substitution process and determines the requirements for material in case of substitution.

1.1 Backround

The subject of this thesis became more crucial; since the recent global events have shocked the world and caused problems in the availability of raw materials. Availability issues started with the COVID-19 pandemic, but overall, for example in silicone industry it is the sum of many factors such as supply demand change, labor layoffs, energy costs, logistics and pricing. (Melito, 2021; Testo, 2021.) Companies have worked hard to get raw materials for their needs and, in the best case, alternative materials for the products have also been determined.

At the center of Sitra´s megatrends 2023 is the ecological sustainability crisis and the erosion of nature’s carrying capacity: the climate is heating up, biodiversity is declining at an alarming rate, natural resources are being overused and waste is increasing. Human activity places a burden on living and non-living nature that exceeds its carrying capacity, thereby compromising the very basis of our economy and well-being. (Wartiovaara, 2023.)

Businesses today are becoming more conscious of the importance of circular economy principles and sustainable business models. In the manufacturing industry, there is a growing focus on maximizing material productivity and energy efficiency, while also striving to reduce or eliminate waste. Manufacturers are recognizing that these practices are key to adopting sustainable business model archetypes, which prioritize waste reduction, increased material productivity, and other environmentally responsible practices (Bocken et al., 2014). To achieve these targets companies must find new ways of doing things and optimize their processes.

The Thesis takes into account both the raw material shortage and the aspects of the circular economy, and if the goal is achieved, they will both improve.

1.2 Aim and limitations of the thesis

The cold shrink accessories, like cold shrink termination and joints are used in underground cables. The insulating silicone layer of cold shrink terminations is composed of liquid silicone rubber, which is both insulating and has tracking resistance. This material is called in this study as Material 2. The silicone insulation of cold shrink underground cable joints is made of solely insulating silicone rubber and in this study is called as Material 1. The objective of this study is to investigate the feasibility of using insulating liquid silicone rubber with tracking resistance, Material 2, in both cold-shrink terminations and joints. The utilization of only insulating silicone rubber in both termination and joint, Material 1, was not considered in this study because the material utilized in the cold shrink terminations must withstand tracking resistance.

Liquid silicone molding machines are used to mold silicone terminations and joints. When switching from Material 2 to Material 1, the machine needs to be thoroughly cleaned, which involves purging the old material out of the machine with the new material. This purging process generates a significant amount of waste material that cannot be reused or currently recycled. If the goal of using only Material 2 in both terminations and joints is achieved, the process time would be reduced and less waste material would be generated. This is because the cleaning process performed when changing the material of the molding machine could be skipped.

1.3 Research method

The thesis is divided into two parts: theory and experiment. In the theory part, the purpose and use of cold shrink terminations and joints are explored, as well as the requirements and standards that define them. The manufacturing process and molding techniques used are also discussed, along with material requirements and testing methods for both mechanical and electrical properties. Additionally, the theory part delves into the material substitution process and the requirements involved in changing materials.

The experimental part focuses on studying the properties of materials through laboratory experiments. The research begins with defining the material properties such as tensile strength and elongation at break, tear strength, volume resistivity, hardness and dielectric strength. Material properties are verified by laboratory tests with test samples made from silicone sheet samples. The investigation is continued with the products manufactured in production. In the final stage of testing, genuine products are used, which are physically installed on the cable. This crucial step ensures that the products work in the intended system.

The conclusion brings together the entire thesis and takes a stand on the material substitution process.

2 Background theory

In this chapter, a brief historical overview of the underground cable network is provided. Following that, a detailed explanation of underground cable accessories, particularly cable joints and terminations is also provided. While discussing the theory of these two accessories, primary focus will be on the insulating silicone material that is used in cold shrink joints and terminations.

2.1 History of MV undeground cable network

Francis Ronalds carried out the first experiments that eventually led to the development of an underground cable network system in 1819. The experiment was the distribution of telegraphs through underground lines. After that, the underground line tests increased, some were successful and some were not so successful. The development of street lighting accelerated the development of underground cables to distribute electricity to street lights instead of overhead wires that were prohibited in some cities. (Thue, 2017.)

Medium voltage (MV) distribution networks are used to distribute electricity between low and high voltage systems (Lakervi & Holmes, 2003). The first MV underground cables were installed in 1890 that led to creation of MV distribution network. The development of cross-linked polyethylene and its use as jacket material in MV cables accelerated the construction of the underground cable network. (Thue, 2017.) With urbanization, the underground cable network continues to expand, but the expansion is also affected by the lifetime of the underground cable network, which is longer compared to overhead lines that are more sensitive in case of failure. (Lakervi & Holmes, 2003.)

2.2 MV cold shink underground cable accessories

To be able to join two underground cable ends together or to terminate the underground cable, underground cable accessories are needed. Accessories are combined to underground cables forming a combined system. For that reason accessories need to withstand same electrical stress concentration as the cable itself. (Thue, 2017.) The use of underground cable accessories sets both electrical and mechanical requirements for the materials used in underground cable accessories. Joints and terminations must not only provide adequate insulation, but also provide stress control for screened cables, mechanical protection, especially for joints, and environmental protection for terminations. (Moore, 1997.) The silicone insulation of cold shrink accessories needs to be electrically insulating with good dielectric strength. The insulation layer not only mechanically protects the cable and connector but also prevents water from entering inside the joint or termination. (Thue, 2017.)

Cold shrink accessories are developed to provide a pre-fabricated product to eliminate as much handling as possible in the field, where the accessories are used and installed. Less handling in the field reduces the number of installation errors. Cold shrink joint is presented in Figure 1. The joint is expanded over the support.

Figure 1. Cold shrink joint expanded over the support.

Cold shrink termination is presented in Figure 2. The termination is expanded over the support.

Figure 2. Cold shrink termination expanded over the support.

Cold shrink joints and terminations are pre-stretched on a support that is several times larger than the needed diameter. During installation, expanded accessories are slid over the cable and after positioning, the support is removed and the accessories will shrink close to their original size. No heat is needed during installation. (Cheenne-Astorino & Chatterjee, 1996.) Cross-sectioned cold shrink joint with geometrical stress control is presented in Figure 3.

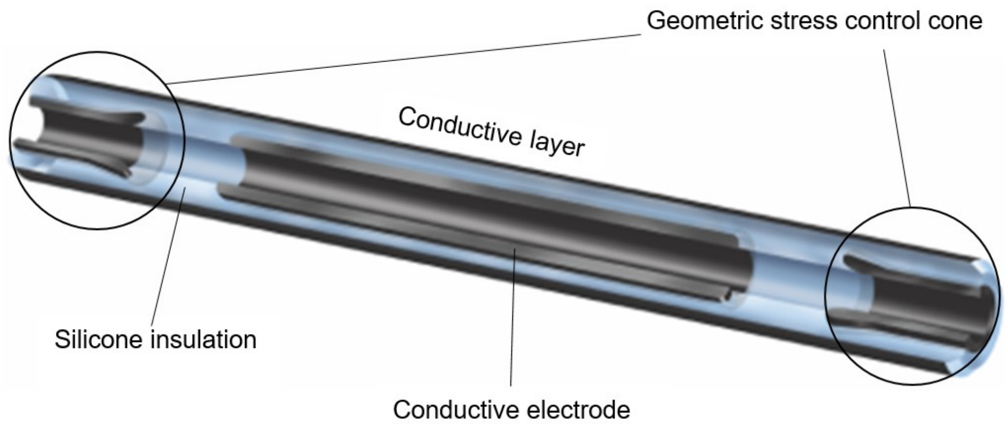


Figure 3. Cross-sectioned cold shrink joint.

Cable accessories needs stress control to withstand both electrical stress, that is developed when the cable geometry has changed, and to perform electrically. There are many stress control techniques, but modern cold shrinks accessories uses mainly geometrical stress control. Geometrical stress control, simple stress relief, is already placed in pre-fabricated products. Geometrical stress control is implemented with cone shape conductive stress control cone that is placed at the edge of the cable insulation shield. With the help of stress control cone, the electric field spreads more evenly, which eliminates the possibility of partial discharges. (Thue, 2017.) Pre-fabricated geometrical stress control is presented in Figure 3. Stress control cones can be found in both ends of the cold shrink joint.

2.3 Cold shrink terminations, insulation material

Underground cable terminations are discussed when cut end of the cable or conductor needs to be terminated and connected to other component of the network. The terminations are classified as either outdoor or indoor terminations. (Cheenne-Astorino, & Chatterjee, 1996.) Outdoor terminations are exposed to UV radiation and weathering, while indoor terminations are exposed to humidity. Therefore, the termination needs to withstand tracking to prevent surface discharges. (Väkeväinen, 2015.) Cold shrink outdoor terminations with mechanical lugs are presented in Figure 4.

Figure 4. Cold shrink outdoor termination with mechanical lugs (Ensto, COT1.2403L, 2023).

To be able to withstand weathering and ultraviolet (UV) radiation, tracking resistance is needed (Cheenne-Astorino, & Chatterjee, 1996). Beside termination main function, connecting the cable end to another connection point, it needs to prevent water or moisture to entering inside the termination and mechanically protect the cable end (Thue, 2017).

2.4 Cold shrink joints, silicone insulation

Underground cable joints are discussed when two underground cable ends are joined together with a connection between (Thue, 2017). Cross-sectioned medium voltage underground joint is presented in Figure 5. The two ends of the cable are joined together using a mechanical connector, and a cold shrink joint is installed on top.

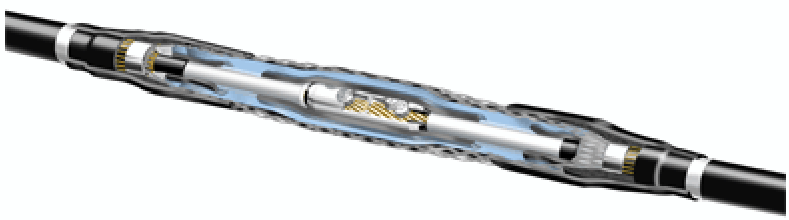


Figure 5. Cross-sectioned cold shink joint for one core cable with mechanical connector (Ensto, CJ11.2403C, 2023).

Insulation material for cold shrink joint must safely withstand intended electrical stress, prevent water from entering the cable and the connector and protect the cable mechanically (Thue, 2017).

2.5 Product requirements

The insulation materials for cold shrink joints and terminations need to withstand high electrical stress while preventing water from entering the cable and providing mechanical protection to the cable. Terminations also need to withstand weathering and UV radiation, which requires the material to have tracking resistance. Joints can be viewed as terminations that are connected to each other. (Thue, 2017.) Because of that it can be assumed that the insulating material used in cold shrink terminations can also be used in cold shrink joints. To approve the substitution of the material, both material tests and electrical tests are required, but it is also necessary to investigate any differences between the two materials when the joint is expanded on top of the support and also when the support is removed.

3 Silicone rubber

In this chapter, a brief overview of the history of silicone rubber is provided and the chemical composition and various properties of polydimethylsiloxane (PDMS) is discussed. Subsequently, focus is on the liquid silicone rubber (LSR), which is widely used in liquid injection molding (LIM), and examine the environmental impact of silicone rubber.

3.1 History of silicone rubber

The name silicone was established in 1901 by Kipping. The name silicone described the new compound of generic formula R2SiO. Silicone is a polymer that contains silicone, carbon, hydrogen and oxygen. Silicone is a rubber like elastomer with excellent heat resistance, chemical stability and very good weather and UV resistance. Silicone is also electrically insulating by nature and has good abrasion resistance. (Shit & Shan, 2013.) Due to silicone excellent electrical insulation behavior and weather resistance, silicone is widely used in cold shrink cable accessories (Polmanteer, 1988).

First commercially available silicone rubbers were published in 1944. At the time, those weak polymer gels were developed to be stronger polymer gels. Over time, the development of silicone rubber grew strongly and there was a huge commercial impact when the tensile strength of silicones increased due to the use of vinyl groups. After the tensile strength was achieved, focus was to improve also tear strength, toughness and flammability that came with the help of RTV (room temperature vulcanization) hydroxylation chemistry. In 1966, Dow Corning Corporation introduced a silicone with high tensile strength, high tear and good resilience, which was created by mixing high and low vinyl-containing polymer molecules and polymers. (Polmanteer, 1988.)

3.2 PDMS

Polydimethylsiloxanes (PDMS) are and have been for decades the most common silicone polymers in silicone elastomer technology. Figure 6. presents an easily accomplished manufacturing process of polydimethylsiloxane, using coke, quartz, chlorine and water. (Polmanteer, 1988.)

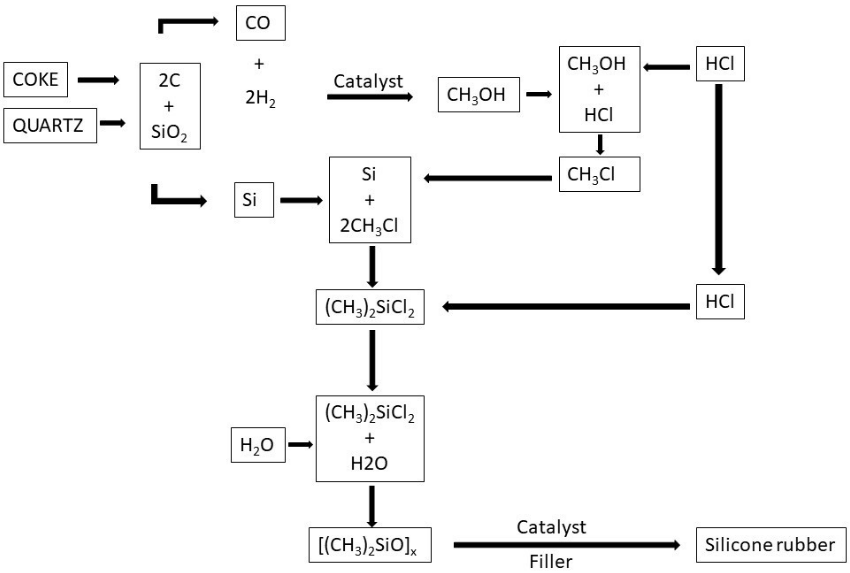


Figure 6. Manufacturing of polydimethylsiloxane from coke, quartz, chlorine and water (Adapted Polmanteer, 1988, 484).

The chemical formula of PDMS is presented in Figure 7. The amount of siloxane repeating units, in chemical formula described with letter n, varies depending of the silicone type (Polmanteer, 1988).

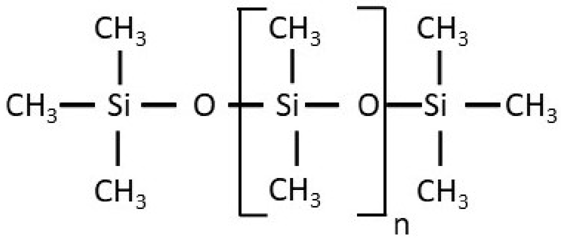


Figure 7. Chemical formula of polydimethylsiloxane (Adapted Polmanteer, 1988, 472).

The amount of siloxane repeating units varies in high consistency silicone rubbers between 3000 to 5000 and in LRS and RTV silicone rubber it varies between 50 to 2000 units (Polmanteer, 1988).

3.3 Properties of silicone rubber

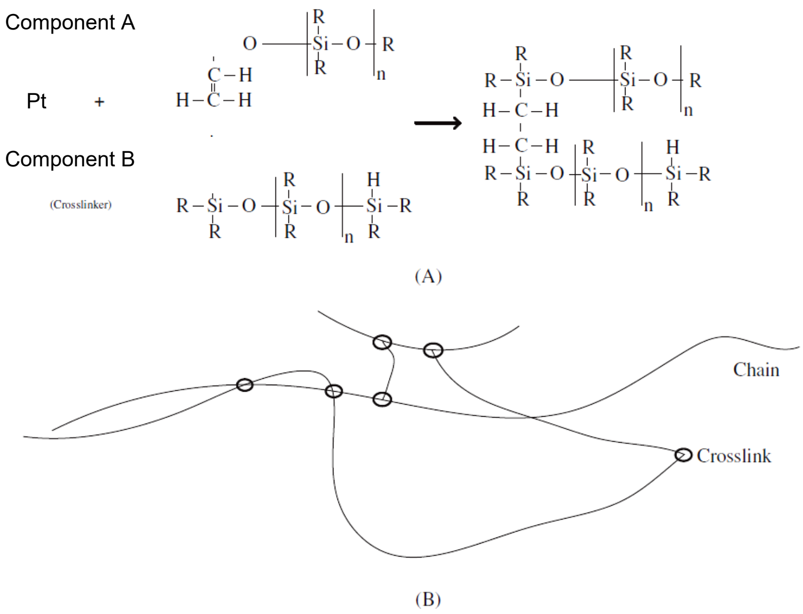
Silicone rubber has good mechanical, physical and electrical properties that can be explained with the chemical structure of silicone rubber. Silicone rubber has good heat resistance, which is the result of high binding energy of siloxane (Si-O) bonding. Si-O bond has a binding energy of 106,0 kcal/mol that makes silicone rubber chemically stable with the heat resistance and electric conductivity better than in ordinary organic rubbers. Ordinary organic rubbers are based on carbon-carbon bonds, C-C bonds, with binding energy of 84,9 kcal/mol which is much less than Si-O binding energy. (Shit & Shan, 2013.)

High elasticity, high compressibility and ability to resist cold temperatures is due to low helical and intermolecular force of silicone. Good weather and water resistance is due to methyl groups that are located outside the coil structure and are able to rotate freely. (Shit & Shan, 2013.)

3.4 Liquid silicone rubber

The first commercial LSRs (liquid silicone rubber) were introduced in 1976-77 thanks to a combination of technology, fabrication and new marketing advantages (Polmanteer, 1988). Commercial LSR is based on PDMS structure, siloxane backbone and methyl side group (Bont et al., 2021).

LSR is usually a two-part system, which one part contains Platinum (Pt) catalyst. The curing occurs due to the combined effect of two components and the heat. Low injection pressure and pressure forming systems are usually used. (Shit & Shan, 2013.) Chemical structure of two component LSR using Pt catalyst is presented in Figure 8. Component A contains the Pt catalyst and component B contains the cross linker and an inhibitor. Both components contain the polymer itself and fillers. (Bont et al.,2021.)



(A) presents the chemical crosslinking reaction of component A + B. (B) presents already cross linked structure of LSR.

Figure 8. Crosslinking reaction of platinum cured LSR (Bont et al., 2021).

LSR properties can be modified with the different variations of side groups and side group concentrations, chain length distribution, silica filler content and with different additives, but the structure, concentration and additive ratio is usually only known to LSR manufacturers (Bont et al., 2021).

3.5 Environmental aspect of silicone rubber

It has been studied that waste PDMS is very easily absorbed to sludge and high PDMS concentrations have been found in the sludge. Several studies have shown that PDMS is inert to wastewater treatment and is poorly degradable. This research is strongly supported by the chemical nature and high molecular weight of PDMS. PDMS ends up in wastewater mainly in liquid form and thus it is not considered such a big risk in solid bodies. On the other hand, studies have also shown the potential degradation of PDMS in soil and sediments under the right conditions, although a rather slow degradation. Levels of impact on terrestrial, aquatic and benthic organisms have also been investigated, and they did not indicate any potential environmental risks. (Fendinger et al., 1997.)

The first environmental concerns emerged from the use of silicone in wash-off cosmetics, especially the use of octamethyltetracyclosiloxane (D4), decamethylpentacyclosiloxane (D5) and dodecamethylhexacyclosiloxane (D6). The use of D4 and D5 was finally restricted in wash-off cosmetics in 2015 and resulted in D4, D5 and D6 being added to substances of very high concern (SVHC) candidates list. (ECHA, 2018.) In wash off cosmetics, silicone containing products were washed out and silicone, together with volatile organic silicon compounds (VOSiC) D4, D5 and D6 were drained to waste water, from where substances were easily absorbed to sludge from where it will be a risk to the environment (Fendinger et al., 1997).

D4, D5 and D6 are cyclic volatile methyl substances that contain four, five or six siloxane groups. Those three VOSiC, D4, D5 and D6 have been added to Registration, Evaluation, Authorization and Restriction of Chemicals (REACH) SVHC candidate list in June 2018. D4 meet the criteria of Persistent, Bio accumulative and Toxic (PBT) substances and D4, D5 and D6 meet the criteria of very Persistent, very Bio accumulative (vPvB) substances. Also together with D4 and when concentration exceeds the limit of 0,1%, D5 and D6 are classified as PBT. This identification, the identification of an SVHC substance in the SVHC candidate list, obliged manufacturers and importers to implement risk management that minimizes the risks to people and the environment and covers the entire life cycle of the object or product. (ECHA, 2018.)

D4, D5 and D6 are present as impurities, residuals in LSR, with no intended function, but are the key monomers that are used to produce silicone rubber. With current technology, it is not possible to produce silicone rubber with zero content of D4, D5 and D6, but with the right technique, it is possible to minimize the content. (ECHA, 2018.) With proper post-curing of the molded silicone product, uncross linked siloxane and VOSiCs can be eliminated or significantly reduced (Jehbco Silicone 2019).

4 LRS injection molding

In this chapter, the focus will be on the material substitution process, specifically in the context of cold shrink accessories for underground cables. The technical performance will be examined of the two materials in question, while also considering their compatibility with surrounding materials. Moreover, the potential economic benefits and environmental implications of this substitution process will explored.

4.1 Liquid silicone injection molding

Main structure of LRS injection molding is presented in Figure 9. Usually LSR is provided as two component system, Part A (compound A) and Part B (compound B) that were described in earlier chapters. Both parts A and B contain specific chemistry. Compounded together with additional additives or colors are pumped into the static mixer. Color range varies typically from 0,3% to 6,0 % and additives range can be more than 5,0 %. (Bont et al., 2021.)

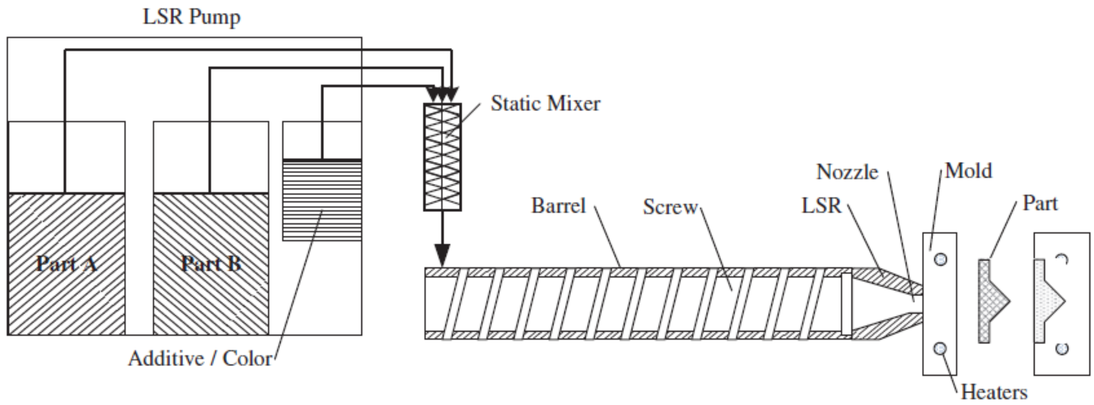


Figure 9. Main structure of LSR injection molding process (Bont et al., 2021).

From the static mixer, already mixed LSR is fed into the barrel where the screw keeps shearing the silicone. To avoid any premature vulcanization, the barrel is usually cooled under room temperature. Generally shear speed of the screw is around 50 – 200 RPM. Screw pushes the silicone towards the injection unit, where cold runner system is usually used to avoid premature curing in the gate and runner. From the injection unit, the silicone is pushed trough a nozzle to the hot mold. Injection pressure varies normally from 1 MPa to 80 MPa, but also higher and lower pressures are used. Commonly used mold temperatures varies between 120 °C to 160 °C. (Bont et al., 2021.)

LSRs experience a thermal expansion, LSR warms up in contact with hot mold and with that, cavity pressure increases. Depressurizing occurs through flashing and through backflow to the gate and through overflow area. To reduce flashing, packing pressure should be minimized tough this will increase the shrinkage of the product. To get the best solution for the product some optimization needs to be done. Holding pressure is commonly used to prevent backflow, but in cold runner systems, pneumatic valve gates are commonly used to prevent backflow into the nozzle. (Bont et al., 2021.)

Curing time, also called vulcanization time, depends of the thickness, used material and the mold temperature. For commercial LSR, curing time often varies between 3 - 7 s per millimeter of wall thickness, when temperature is higher than 140 °C. The lower the temperature the longer the curing time. (Bont et al., 2021.)

4.2 Vulcanization

Vulcanization, also known as curing or crosslinking, takes place with the help of a Pt catalyst. Pt catalyst breaks the double bond of the vinyl group and allows the cross linker to form new bonds to create a network structure. Typical cross linker in commercial grades of LSR is short chain polyorganosiloxane. Vulcanization process is critical in LSR injection molding process, since it improves material properties like tensile strength and heat resistance. The presence of inhibitor is also part of the vulcanization process of LSR. Inhibitors prevent premature vulcanization, in other words prevent chemical reaction between compound A and B by blocking the catalyst and slowing the reaction. The inhibitor is usually placed in compound B. (Bont et al., 2021.)

The amount of Pt catalyst varies between different commercial grades of LSR and is shown to be 10-15 parts per million. Used heat accelerate the reaction and typically, used heat is between 140 °C to 200 °C. Vulcanization is finalized when LSR becomes elastic to solid. (Bont et al., 2021.)

4.3 Post-curing

While some literature suggests that LSR does not require post-curing, it's important to note that the necessity of post-curing is dependent on several factors. These factors include the specific material used, the product that is produced, and the intended use of the final product. Therefore, it's essential to assess each individual case to determine whether or not post-curing is required.

Post-curing is done to complete the curing process, which in vulcanization state falls a little short, approximately 75-90%. With post-curing, tensile strength, elongation at break and tear strength usually improve, but experimental testing is usually required to determine the minimum duration and temperature of the post-curing. Typical post-curing conditions and the conditions that silicone manufacturers recommend is 4 hours at 200 °C. (Bont et al., 2021.)

4.4 Silicone rubber in cold shrink cable accessories

Due to silicone rubber´s good mechanical, thermal and electrical properties, not to mention excellent weather ability such as UV, ozone and rain resistance, silicone rubber is widely used in cold shrink cable accessories. Cross-linking creates complex network structures (Bont et al., 2021). Network structures create memory for the silicone rubber. Thanks to the memory, the silicone rubber used in cold shrink cable accessories can be expanded over the support and after support removal it shrinks back close to its original shape.

Silicone rubber withstands use from -70 °C to over 200 °C which is much more than typical organic rubber can withstand (Shit & Shan, 2013). For example, EPDM rubber that is also used in cold shrinks can withstand the temperature range of -40 °C to 140 °C (Bont et al., 2021).

Typically silicone rubber, depending on the of silicone and additives in use, has a tensile strength of 9 kN/m and a tear strength of 29 kN/m – 49 kN/m (Lamier, 2019). The elongation at break of commercial LSR grades varies from less than 200% to more than 1200% and a majority of grades have 20-70 Shore A hardness (Bont et al., 2021).

4.5 Technical performance of silicone rubber used in cold shrink accessories

The mechanical properties of LSR, along with its electrical properties, determine LSR´s suitability for use in cold shrink joints and terminations. While there are commercially available grades of LSR, it's important to assess their compatibility with the process and product design through separate testing.

To ensure the suitability of LSR for use in cold shrink joints, specific requirements have been established for the technical data of commercially available LSR grades. These requirements are outlined in Table 1.

Table 1. Requirements for material properties for insulating silicone rubber used in cold shrink joints.

Material properties	**Test standard:**	**Min**	**Max**
Viscosity [Pas]	DIN 53018 or similar	200	500
Elongation at break [%]	ISO 37 or similar	500	
Tensile strength [MPa]	ISO 37 or similar	5,5	
Hardness, shore A	ISO 7619-1 or similar	28	36
Density [g/cm^3]	ISO 1183 or similar	1,08	1,14
Tear strength [kN/m]	ASTM D 624-B	30	

(Continues)

Table 1. (Continues).

Material properties	Test standard:	Min	Max
Volume resistivity [Ωcm]	IEC 60093 or similar	1E+14	
Dielectric strength [kV/mm]	IEC 60243-1 or similar	20	

Specific requirements have been established for the technical data of commercially available LSR grades used in cold shrink terminations. These requirements are presented in Table 2.

Table 2. Requirements for material properties for insulating silicone rubber with tracking resistance used in cold shrink terminations.

Material properties	Test standard:	Min	Max
Viscosity [Pas]	DIN 53018 or similar	100	500
Elongation at break [%]	ISO 37 or similar	450	
Tensile strength [MPa]	ISO 37 or similar	6,0	
Hardness, shore A	ISO 7619-1 or similar	35	45
Density [g/cm^3]	ISO 1183 or similar	1,08	1,14
Tear strength [kN/m]	ASTM D 624-B	20	
Volume resistivity [Ωcm]	IEC 60093 or similar	1E+14	
Dielectric strength [kV/mm]	IEC 60243-1 or similar	20	
Permittivity (50 Hz)	IEC 60250 or similar	2,7	3,0
Dissipation factor (50 Hz)	IEC 60250 or similar	1 x 10^{-3}	
Tracking resistance, class	IEC 60587	1A 4,5	

When comparing the material technical data requirements for each application, the most significant differences are readily apparent. This is primarily because cold shrink terminations require tracking resistance, which is not necessary for cold shrink joints.

Tracking resistance is achieved with different additives. The material supplier usually does not supply the additive used or the additive concentration in the silicone. In the past, achieving high tracking resistance often involved using various alumina compounds. However, nowadays, new solutions have emerged. One such solution is the use of functional silane, which contains hindered amine and urethane groups. This particular silane, known as PPAS, has been found to significantly improve tracking resistance. (Fink, 2019.) However, achieving higher tracking resistance can have a negative impact on the mechanical properties of the material. When considering material substitution, this aspect must be taken into account. Specifically, the elongation at break and tear strength have the most significant effect on the durability and usability of the product.

5 Material substitution

This chapter focuses on material substitution process and especially material substitution process in cold shrink accessories for underground cables. The technical performance of the two materials is studied but also the compatibility of surrounding materials will be discussed. Finally, economic advantages and environmental aspects are discussed.

5.1 Material substitution process

When considering material substitution, care must be taken to ensure that all aspects have been taken into account. Substituting to a new material have caused a large amount of failures that are related to the fact that the new material was not well known and properly tested before substitution. Common causes of the failure include long-term material properties that were not fully known and material substitution without reviewing the design. Materials have to be mechanically, physically and chemically compatible with surrounding materials to avoid any failure related to compatibility. (Farag, 2008.)

In his article, Farag (Farag, 2008.) has divided the main parameters for substitution process into four main groups:

a) Technical performance advance

b) Economic advantage, the total advance over the total life cycle of the product

c) Aesthetic view, changing the character of the product by incorporating the material that is aesthetically more attractive

d) Environmental and legislative aspect, less damage to the environment, better recyclability or reuse and compliance to environmental regulations

As the material under consideration for substitution is already utilized in cold shrink termination, my study will primarily concentrate on evaluating its technical performance. However, I will also briefly consider the potential economic advantages, as well as the environmental and legislative implications associated with the substitution process.

5.2 Technical performance

Technical data of Material 1 and Material 2 materials were compared as a pre-study of the substitution process. Pre-study was done to understand whether it is even technically feasible, when mechanical and electrical aspects are taken into consideration, to substitute Material 1 with Material 2.

Technical data of Material 1 is presented in Table 3. Raw material supplier informs mixing ratio of components A and B to be 1 : 1 and the mechanical properties were measured on 2 mm thick test sheets with vulcanization of 10 minutes at 175°C in an oven and post-curing 4 hours at 200 °C.

Table 3. Technical data of Material 1.

Material properties	**Test standard:**	**A-part**	**B-part**
Viscosity [Pas]	DIN 53018 or similar	300	300
Elongation at break [%]	DIN 53 504 S2	700	
Tensile strength [MPa]	DIN 53 504 S2	8	
Density [g/cm^3]	DIN 53 479 A	1,1	
Tear strength [kN/m]	ASTM D 624 die B	35	
Compression set [%]	ISO 815	15	

While the technical data for Material 1 does not include information on its hardness, volume resistivity, and dielectric strength, these properties are crucial for the application and have already been defined during the material approval process. It's important to compare these properties with those of Material 2.

Technical data of Material 2 is presented in Table 4. Raw material supplier informs mixing ratio of components A and B to be 1 : 1 and the mechanical properties were measured on 2 mm thick test sheets with vulcanization of 10 minutes at 175°C in an oven.

Table 4. Technical data of Material 2.

Material properties	**Test standard:**	**A-part**	**B-part**
Viscosity [Pas]	DIN 53019-1	300	250
Elongation at break [%]	DIN 53 504 S2	800	
Tensile strength [MPa]	DIN 53 504 S2	12	
Hardness, shore A	DIN 53 505	39	
Density [g/cm^3]	DIN 53 479 A	1,11	
Tear strength [kN/m]	ASTM D 624 die B	26	
Volume resistivity [Ωcm]	DIN 53482	5E+15	
Dielectric strength [kV/mm]	DIN 53481	25	
Dielectric constant	DIN 53483 (50 Hz)	2,8	
Tracking resistance, class	IEC 60587	1A 4,5	

Upon comparing the technical data of the two materials, it becomes evident that Material 2 is a stiffer material with lower tear strength than Material 1. Although the data for Material 1 does not present the values for hardness, volume resistivity, and dielectric strength, these material properties were taken into account when selecting the material for this specific application. Therefore, it is crucial to compare these properties with those of Material 2 to obtain a comprehensive understanding of the materials' suitability for the product. In Table 5. both material data are compared to each other and also compared to the Material 1 technical data requirements.

Table 5. Technical data sheet comparison of material properties of Material 1 and Material 2 .

Material properties	**Test standard**	**Min**	**Max**	**Material 1**	**Material 2**
Viscosity [Pas]	DIN 53018 or similar	200	500	300	300/250
Elongation at break [%]	ISO 37 or similar	500		700	800
Tensile strength [MPa]	ISO 37 or similar	5,5		8	12
Hardness, shore A	ISO 7619-1 or similar	28	36		39
Density [g/cm^3]	ISO 1183 or similar	1,08	1,14	1,1	1,1
Tear strength [kN/m]	ASTM D 624-B	30		35	26
Volume resistivity [Ωcm]	IEC 60093 or similar	1E+14			5E+15
Dielectric strength [kV/mm]	IEC 60243-1 or similar	20			25

Upon comparing the properties to the requirements, it was observed that the tear strength of Material 2 did not meet the demands. Despite this observation, the investigation was carried out as other factors, such as economic advantages and environmental considerations, also needed to be taken into account.

5.3 Economic advantage

The primary focus of this chapter regarding the substitution process will be on the economic advantages, which encompasses both the material cost as well as the processing cost. The latter includes the entire manufacturing process of cold shrink accessories, as well as the waste material that is generated when the material is switched to the injection molding machine.

Taking into account the available information, it is evident that choosing Material 2 is currently the more cost-effective option if it is possible to achieve the desired electrical functionality with Material 2. Material 2 offers a favorable balance between its electrical performance and cost considerations. This assessment takes into account factors such as the cost of the material, manufacturing processes, and any associated expenses. If the same material is used in both cold shrink joints and terminations, there would be no need to clean the injection-molding machine, which takes labor time. Moreover, the waste generated from purging the injection-molding machine could be eliminated when using the same material for both products. The cost and savings calculations with direct and indirect savings are presented in Table 6. Savings have been calculated based on a weekly material change interval.

Table 6. Cost and savings calculations with direct and indirect savings when Material 1 is substituted with Material 2.

Material savings, generated waste /year	**Production saving, worktime /year**	**Material cost saving**	**Total**
5 500 - 8 300 €	1 400 €	113 300 €	120 000- 123 000€

Based on the calculations, it can be concluded that the most significant effect is the material price. Yearly saving due to material substitution would be over 120 000 €.

5.4 Environmental and legislative aspect

From an environmental and legislative perspective, the material substitution is evaluated based on compliance with environmental regulations and the environmental impact of the material.

The substance of concern in articles as such or in complex objects, products (SCIP) notification must be done if the concentration of VOSiCs, D4, D5, and D6, exceeds 0.1% in the product. According to the material safety data for

Material 1, D4 concentration is lower than 0.1%, but with Material 2, D4 concentration is lower than 0.25%, which exceeds the limit and necessitates the SCIP notification to ensure the safe use and end-of-life of the product.

After discussing with the raw material manufacturer of Material 2, it was confirmed that D4 content is in injection molded product usually below 0.1%. After post-curing, the content will decrease to 2% of its original content. Therefore, even with as high as 0.25% content of D4 in the raw material, the content will drop below 0.1% after molding and post-curing.

Based on secondary data provided by Ecoinvent 3.9.1 or Sphera GaBi data representation for the period of 2020-2023 in the EU, it has been determined that the global warming potential (GWP) for silicone raw material is relatively high. GWP of liquid silicone rubber or silicone sealing compound or silicone product can vary from 6,5-16 kg CO_2 e/ kg material. These values have been obtained from accredited datasets used in the Ensto's life cycle assessment projects in collaboration with external consultancies. For comparison polypropenes GWP is around 2 kg CO_2 e/ kg material, before use phase and impact from end-of life treatment according to the same sources. Unfortunately, primary data is not offered by manufacturer that holds more specific information from the current state of the process of the platinum-cured silicones made in Europe. Even though the GWP is relatively high, according to the raw material manufacturer the choice of material does not affect the life cycle assessment (LCA) since both raw materials are manufactured in Europe and are platinum-cured silicones. In terms of environmental impact, Material 1 and Material 2 are comparable.

6 Research methods

This chapter provides a detailed explanation of the theoretical background of the conducted research methods.

6.1 Mechanical properties

The mechanical properties of polymers can vary significantly depending on the specific type of the polymer. E.g. the polymer type, molecular structure and weight, used additives and color amount and type affect mechanical properties. In addition to the material properties, the manufacturing process and the testing procedure also play a large role in the mechanical properties. Almost all polymeric applications require the part to withstand some degree of mechanical loading, and therefore mechanical properties are considered the most important properties of polymer design. (Campo, 2008.)

Cold shrink termination and joints aren´t exception in this regard. Cold shrink products are expanded on to a support which means no tools are needed for installation. During the installation phase, the support is removed and the cold shrink shrinks to its pre-stressed size.

The most important mechanical properties of cold shrinks are tensile strength, elongation at break, tear strength, hardness and tension set. Strong mechanical properties are needed to prevent damage that can occur when the insulating material in use is subjected to vibration shocks and mechanical stress (Campo, 2008).

6.1.1 Tensile strength and elongation at break

The tensile test is one of the most widely used testing method for measuring the mechanical properties of a polymeric material. Standardized test determines the stress-strain curve in tension. This is usually done by continuously measuring the force that develops as the test specimen is elongated at a constant rate of extension. (Campo, 2008, 41-50.)

The test specimen is positioned vertically between the grips of the testing machine and the grips are tightened evenly and firmly to prevent any slippage. As the tensile test specimen elongates, the resistance of the specimen increases and is detected by a load cell. The instrument of the testing machine records this load value (force). Usually the elongation of the specimen is continued until the specimen ruptures or breaks. (Campo, 2008, 56-57.)

6.1.2 Tear strength

Tear strength measures a material’s ability to resist failure by tearing. For polymers such as silicone, this is determined by measuring the speed of growth of existing cracks when the material is placed under tension. This is measured in Newton's of tensile force per millimeter of product thickness. (Jehbco Silicone 2017.)

6.1.3 Hardness

Hardness test is the most relevant indentation test for rubber materials and it is widely used to evaluate the material properties from elastomers (Zhao, 2015). Hardness test, also called surface hardness, result describes the materials ability to resist the indentation when the tool, intender, is pressed against the material. Durometer Shore A and D are in use for polymeric materials. The main difference between Shore A and D is the shape and size of the intender. Softer polymeric materials, like silicones, the hardness tester Durometer Shore A is used. Unlike metals, the hardness results obtained from polymer materials do not tell about abrasion or wear resistance. (Campo, 2008.)

Displacement data is converted into hardness values with mathematical scale, used range is 0 to 100 (Zhao, 2015).

6.2 Material electrical properties

Polymer materials, such as plastics and over the last two decades, also silicones, have increasingly replaced traditional materials like mineral oils and ceramics in the energy distribution field. This is due to polymers ease of fabrication, low cost, lightweight and outstanding insulation properties. The most relevant electrical properties for insulating materials are dielectric strength, surface and volume resistivity, dielectric constant i.e. permittivity, dissipation factor, power factor and arc resistance. Those properties are needed to withstand the electrical field between conductor and insulator, to prevent damage if arcing occurs and to have high insulation resistance to prevent leakage current. (Campo, 2008.)

In this case, too, cold shrink termination and joints are no exception. The most important electrical properties and properties that are studied in this thesis are dielectric strength and volume resistivity.

6.2.1 Dielectric strength

Dielectric strength, also called breakdown voltage, is the voltage that the material can withstand when placed between two electrodes and the voltage is applied to the material before dielectric breakdown or electrical discharge through the material occurs. Dielectric strength test is used as an acceptance and quality control test. (Campo, 2008.) When measuring dielectric strength it needs to be taken into account that there are many factors that affect on dielectric strength like thickness of the sample, shape of the electrode, rate of voltage increase and surrounding medium (Berger, 2006).

6.2.2 Volume resistivity

Insulators, such as most polymeric materials like plastics, glass and silicones without any special treatment or additives, have high resistivity (Ashby et al., 2007). Volume resistivity is one option to measure how strongly the material resist electrical current. As the name suggests, volume resistivity takes into account the volume of the test piece in question.

When conducting volume resistivity tests on high resistivity materials such as silicones, it's essential to consider the leakage current to prevent obtaining false results. The test method used for high resistivity materials differs from that used for low resistivity materials. Figure 10. shows a three-terminal method, where the guard electrode is in use to avoid leakage current measuring. (Blythe, 1984.)

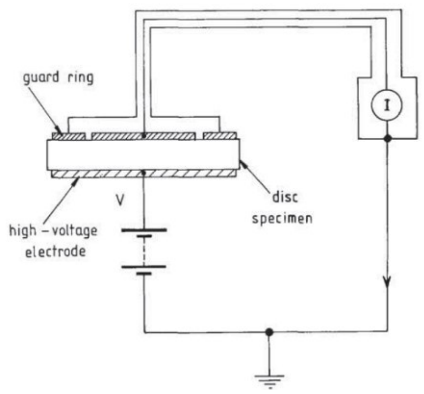


Figure 10. Three-terminal method for measuring volume resistivity from materials with high resistivity (Blythe, 1984).

6.3 Electrical tests

While determining the properties of a material is a crucial step in evaluating substitute or alternative options, the most important step is to ensure that the chosen material performs well in the final product. To verify this, electrical tests must be conducted on the end product.

CENELEC’s harmonization document HD629.1 defines the general test requirements for the medium voltage accessories used on the extruded cables. HD 629-1-S3 specifies the requirement to conduct tests in accordance with the

EN 61442:2005 standard. In this standard, each test is individually described in a dedicated clause.

7 Laboratory tests

Detailed explanation of the laboratory procedures that were followed during the study is provided in this chapter. All laboratory tests were conducted in accordance with standardized methods and followed by laboratory internal instructions. Furthermore, the laboratory complies with the SFS-EN ISO/IEC 17025:2017 standard, and HD629.1 is a FINAS-accredited laboratory test.

7.1 Sample preparations

The test sheet samples used for material testing were obtained from the raw material supplier and post-cured in a 200 °C oven for 4 hours. Injection molded cold shrink terminations, CTSBGEL16, were used as production samples for material testing. Termination size 16 was selected for material testing due to several reasons. Firstly, it is one of the most commonly produced sizes in production, making it a suitable choice for testing. Additionally, the size is easy to work with, as it allows for the easy cutting of samples needed for material testing.

Terminations manufactured with Material 1 were post-cured in a 200 °C oven for 5 hours, while terminations manufactured with Material 2 were post-cured in a 190 °C oven for 3 hours. This difference in post-curing temperature and duration was based on previous research conducted during the selection of Material 2 for use in cold shrink terminations. An example of the termination samples used in the material testing process is presented in Figure 11.

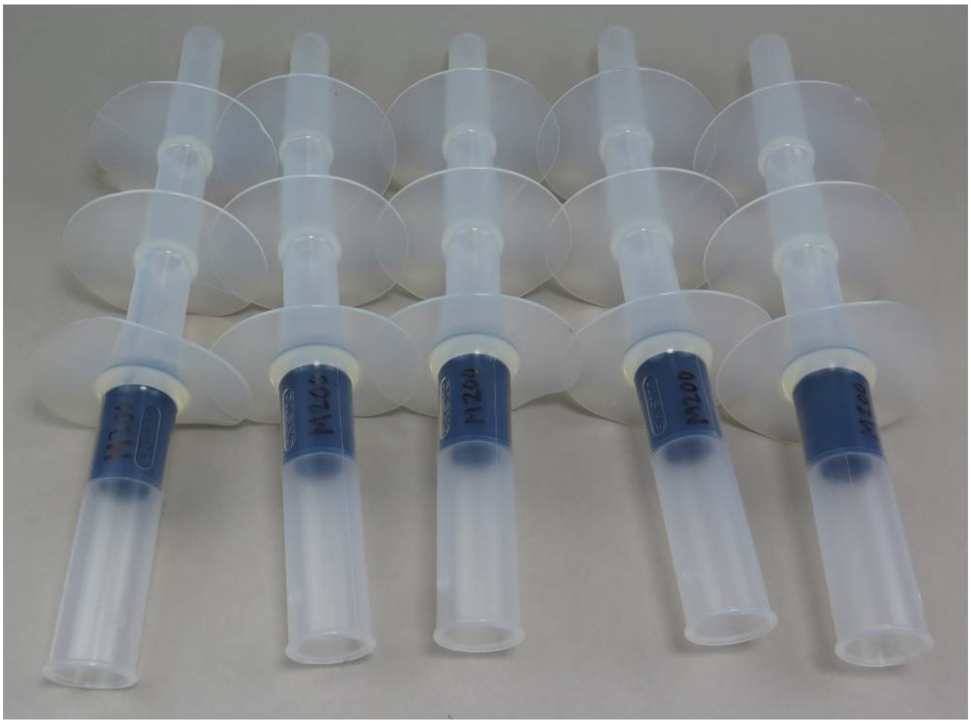


Figure 11. CTSBGEL16 termination samples injection molded with Material 1.

Two different sizes of cold shrink joint samples were manufactured without a conductive outer layer for visual inspection and shrinkage testing. Samples were expanded on a larger support than normal so that the aging behavior would appear more quickly. Cold shrink joint size 16, CSJM16, was chosen due to its common use in production, while size 27, CSJH27, was chosen due to its ability to create the highest pressure on the support.

The CSJM16 joint samples used for electrical testing included a conductive outer layer and were manufactured using Material 2. To ensure optimal performance, the joints were post-cured in a 190°C oven for three hours. The joint samples for electrical testing were installed in accordance with the manufacturer's installation instructions, which can be found in Appendix 1.

7.2 Tensile strength and elongation at break

Silicone rubber samples were measured with Zwick Roell tensile test machine using Zwick longstroke extensometers. The test was done according to ISO 37 and IEC 60684-121 to 124 which are standard methods for vulcanized and thermoplastic rubbers. The standards defines the test sample, size and shape, and the testing procedure. Tensile strength and elongation at break were determined from dumbbell shaped sample, sample type 2, at the room temperature. Five samples were measured at constant rate of extension, crosshead separation speed that was determined in standard to be 500 mm/min with rubber samples.

7.3 Tear strength

Tear strength was measured with the Zwick Roell tensile test machine longstroke extensometers. The test was made according to standard ASTM D624 that describes the procedure of measuring tear strength that is conventional property of vulcanized rubber. Used sample type was type B that defines the maximum force required to cause a nick or cut, in the test piece, to grow by tearing the silicone rubber. Three to five samples were measured at constant rate of extension, with crosshead separation speed that was determined in standard to be 500 mm/min with rubber samples.

7.4 Hardness

In this study Shore A hardness method was used according to ASTM D2240. Hardness was tested with Durometer Zwick Roell Shore A and it was used with the testing stand, both are presented in Figure 12.

Figure 12. Zwick Roell Shore A with testing stand.

The Shore A value was recorded after 15 s because of the settling delay. Five samples were measured from which the average value was calculated.

7.5 Dielectric strength

The test was done according to IEC 60243-1 standard and laboratory instructions. High voltage test device Schleich Portatest A2 is presented in Figure 13.

Figure 13. High voltage test device Schleich Portatest A2.

The high voltage testing device uses a test cell where the electrodes are located. The test cell is presented in Figure 14.

Figure 14. Test cell of the High voltage test device Schleich Portatest A2.

The test were made in transformer oil with the sample thickness of 2 mm.

7.6 Volume resistivity

The tests were done with 2 mm thick sheet sample according to ASTM D257 standard and laboratory instructions using guarded electrode. Measurement device Keithley 6517 B Electrometer and Keithley resistivity test fixture 8009 are presented in Figure 15.

Figure 15. Keithley 6517 B Electrometer and Keithley resistivity test fixture 8009.

7.7 Visual inspection

The visual inspection allows to identify any surface defects or other anomalies that may impact product quality and performance. By examining real products, CSJM16 and CSJH27, it can be ensured that the products meet the required visual standards and specifications.

7.8 Shrinkage test after support removal

The measurement is important in quality control and inspection as it allows to assess the shrinkage stability of the products over time. By measuring the dimensions before and after support removal, any changes in the product's size and shape caused by aging or other environmental factors can be evaluated.

7.9 Electrical tests

Electrical tests were performed to already installed joint by the qualified laboratory personnel according to HD 629-1-S3 table 12, test sequence B1 and with the type of joint I.

Due to limitations such as time constraints and laboratory availability, a comprehensive type test could not be conducted for this thesis as the type tests are time-consuming and costly processes. However, in collaboration with the electrical engineer, the most essential tests that ensure product functionality were selected and performed. These tests were prioritized to meet the objectives of the thesis within the given resources and constraints.

Test that were chosen and made according to EN 61442:2005:

1. AC voltage dry test according to test clause 4.
2. Partial discharge test at ambient temperature according to test clause 7.
3. Impulse voltage test at elevated temperature according to test clause 6.

By selecting these specific tests, the thesis aims to assess critical aspects of the product's functionality, insulation properties, and performance under different electrical stress scenarios.

AC voltage dry test involves subjecting the product to an alternating current (AC) voltage under dry conditions. It helps evaluate the product's ability to withstand electrical stress and ensure its functionality. Test set up is presented in Figure 16.

Figure 16. AC voltage dry test set up.

Partial discharge refers to localized electrical discharges within the insulation. Conducting this test at ambient temperature allows for the assessment of the product's insulation integrity and the detection of any potential partial discharge phenomena. Test set up is presented in Figure 17.

Figure 17. Partial discharge test set up.

Impulse voltage test at elevated temperature involves subjecting the product to high-voltage impulses at elevated temperature. Test set up is presented in Figure 18.

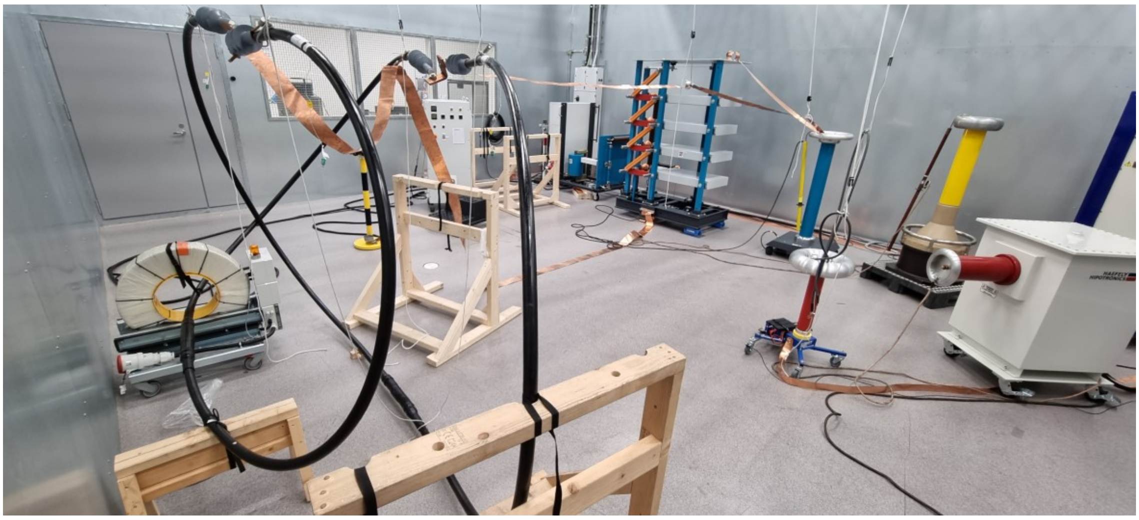


Figure 18. Impulse voltage test set up.

The test evaluate the product's performance under challenging conditions, such as increased temperature, and assesses product´s ability to withstand transient voltage events.

8 Results

In this chapter, I will present the laboratory test results of the material properties for both Material 1 and Material 2. Subsequently, I will provide a more detailed analysis of the tensile strength, elongation at break, and hardness, measured using the Shore A test. Finally, I will present the results of the electrical tests that were conducted using the final product with Material 2, replacing Material 1.

To conduct material property tests, test sheets were obtained from the suppliers of both raw materials. Material verification tests were also carried out on liquid injection-molded (LIM) parts, and the cold shrink termination CTSBGEL16 with the highest production volume was selected for the testing as the necessary test parts could be cut from it. Liquid injection molded samples are called as Material 1. LIM and Material 2. LIM. The average results of all relevant laboratory tests are presented in Table 7.

Table 7. Average test results of Material 1 and Material 2.

Material property	**Min.**	**Max.**	**Material 1. test sheet**	**Material 2. test sheet**	**Material 1. LIM**	**Material 2. LIM**
Viscosity [Pas]	200	500	Not able to test	Not able to test	Not able to test	Not able to test
Elongation at break [%]	500		493	700	543	422
Tensile strength [MPa]	5,5		6,5	15,0	4,9	8,3
Hardness, shore A	28	36	33	36	31	43

(Continues)

Table 7. (Continues).

Material property	**Min.**	**Max.**	**Material 1. test sheet**	**Material 2. test sheet**	**Material 1. LIM**	**Material 2. LIM**
Tear strength [kN/m]	30		30	33	31	30
Volume resistivity [Ωcm]	1E+14		5E+15	1E+15	Not tested	Not tested
Dielectric strength [kV/mm]	10		17	20	Not tested	Not tested

Comparing average results is a good way to start comparing different materials, but a complete knowledge of the material requires deeper research of the most important mechanical properties. Deeper research is presented in specific subchapter.

8.1 Mechanical test results

In this chapter, the key focus is in mechanical properties of the product. Mechanical properties are tensile strength, elongation at break, and hardness. These properties were analyzed in more detail and the results are presented in the following subchapters using box and whisker charts. These charts provide a clear summary of the measurement data and dispersion figures, showing the upper and lower quartiles, the average, and any outliers. Additionally, the matching scaling of the charts makes it easy to compare patterns across the different materials.

8.1.1 Tensile strength and elongation at break

Tensile strength test results are presented in Figure 19.

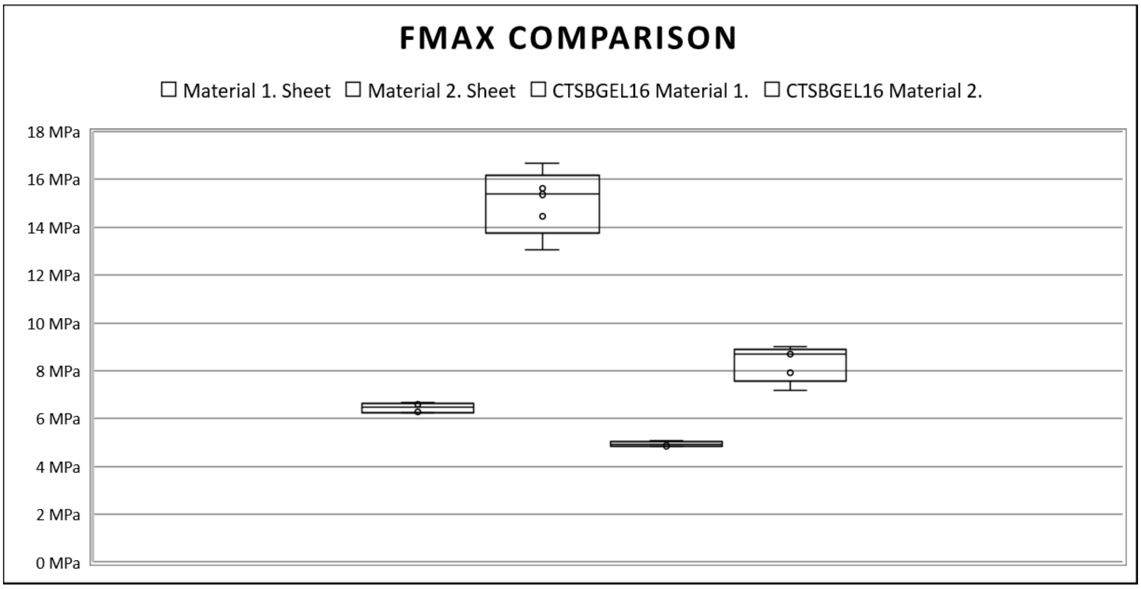


Figure 19. Comparison of tensile strength test results.

Both Material 2 samples, Sheet sample and Material 2 molded CTSBGEL16 sample, have higher tensile strength than samples made of Material 1. The minimum limit for the material is 5,5 MPa. Injection molding weakened the tensile strength of Material 1 and the result is just below 5 MPa.

Elongation at break was analyzed by comparing the test results. Elongation at break results are presented in Figure 20.

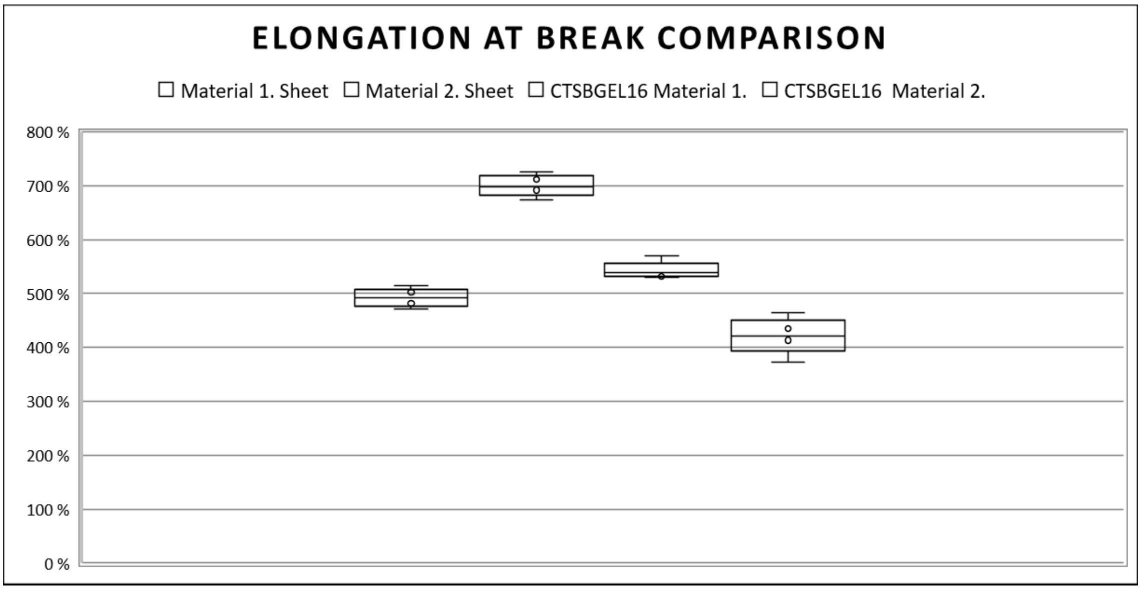


Figure 20. Comparison of elongation at break test results.

Although Material 2 Test sheet shows the highest elongation at break, CTSBGEL16 Material 2 exhibits the lowest elongation at break when injection molded.

8.1.2 Tear strength

To ensure mechanical protection of the cable and the connector, it is important to have sufficient tear strength. The results of the tear strength tests are displayed in Figure 21.

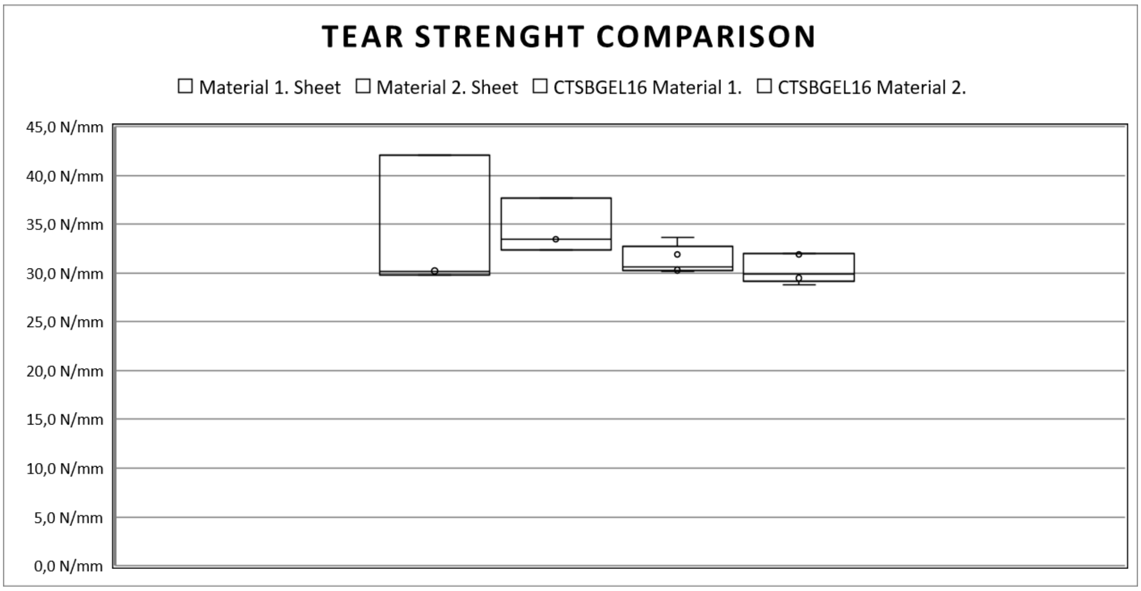


Figure 21. Comparison of tear strength test results.

Average tear strength of injection molded CTSBGEL16 Material 2 is just 30, yet some results are below 30. All other samples have tear strength above 30 that is required in raw material technical data sheets requirements.

8.1.3 Hardness

Hardness test results were analyzed by comparing the test results. Hardness test results are presented in Figure 22. A preliminary study of the technical data sheets found that the hardness of material 2 results exceeded the maximum requirement. Hardness test confirmed that also injection molded samples exceeds the maximum limit.

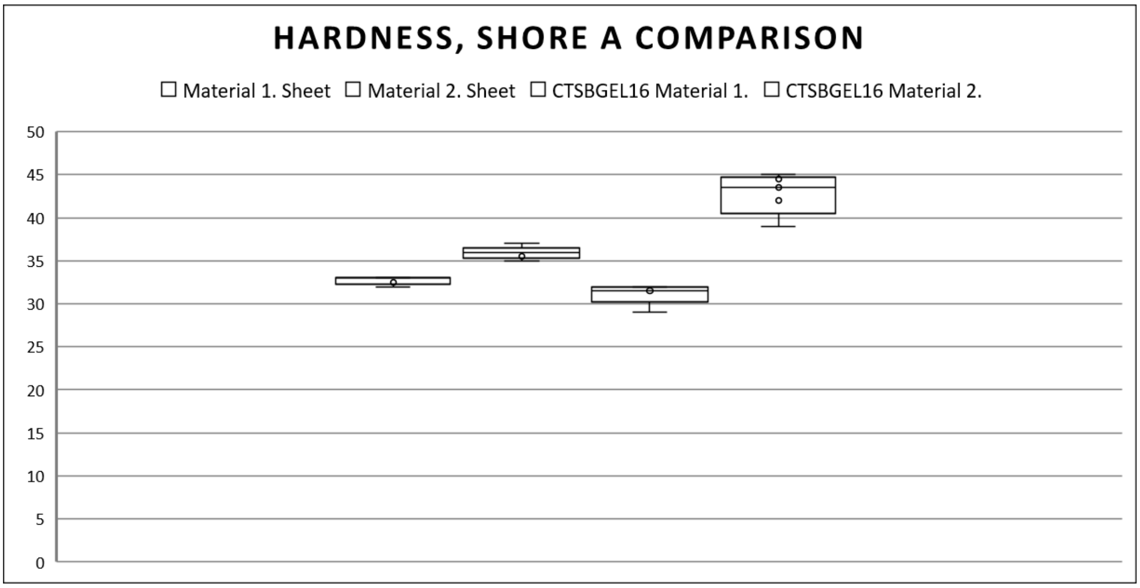


Figure 22. Comparison of hardness, Shore A test results.

Based on the test results, both the Material 2 test sheet results and the CTSBGEL16 Material 2 results exceed the maximum limit of 36.

8.2 Volume resistivity and dielectric strength

In this thesis, volume resistivity and dielectric tests were conducted only on samples made from the test sheet material. Previous experiments have indicated that these properties do not significantly change when the material is injection molded. Average results of volume resistivity and dielectric strength are presented in Table 8.

Table 8. Average results of volume resistivity and dielectric strength.

Material property	**Min.**	**Max.**	**Material 1. test sheet**	**Material 2. test sheet**	**Material 1. LIM**	**Material 2. LIM**
Volume resistivity [Ωcm]	1E+14		5E+15	1E+15	Not tested	Not tested
Dielectric strength [kV/mm]	10		17	20	Not tested	Not tested

Both materials passed volume resistivity and dielectric strength test.

8.3 Visual inspection

Visual examination was conducted on real products without conductive outer layer made from CSJM16 manufactured with Material 2, as well as CSJH27 manufactured with Material 2. Figure 23 shows the visual appearance of CSJM16 after aging without a conductive layer.

Figure 23. CSJM16 sample for visual and shrinkage examination.

Both products passed the visual inspection with no tearing of the silicone nor collapse of the support due to pressure caused by the silicone.

8.4 Shrinkage test after support removal

For shrinkage test, the dimensions of the product were measured before the product was expanded and after support removal, following a period of 1.5 years of aging in expanded conditions. The average results of joint inner diameter was inspected with two different joint sizes. Size 16 joint, CSJM16 was expanded over 3 times it´s inner diameter. Size 27 joint, CSJM27 was expanded almost 3 times it´s inner diameter. The average percentage increase after support removal is shown in the Table 9. for two different cold shrink joint sizes.

Table 9. The average percentage increase after support removal of CSJM16 and CSJH27.

Cold shrink joint	Inner diameter % increase with Material 1.	Inner diameter % increase with Material 2.
CSJM16	+ 32,6 %	+ 19,4 %
CSJM27	+ 10,7 %	+ 10,4 %

Both cold shrink joints showed better shrinkage when manufactured with Material 2, although the difference was less noticeable with larger size cold shrink joints.

8.5 Test results of electric tests for the product

Last material acceptance test is electrical tests for the real product, CSJM16. Test results are presented in Table 10.

Table 10. Electrical test results.

Test of EN 61442	**Clause**	**Requirement**	**Result**
AC voltage dry	4	5 min at 4,5 Uo, no breakdown nor flashover	Passed
Partial discharge at ambient temperature	7	Max. 10 pC at 2 Uo	Passed
Impulse voltage at elevated temperature	6	10 impulses at each polarity, no breakdown nor flashover	Passed

Based on the successful completion of all tests and the passing criteria, it can be concluded that Material 2 is suitable for use in cold shrink joints from the electrical standpoint.

9 Conclusion

Cold shrink accessories for MV underground cables, such as cold shrink joints and terminations, are used either to connect two cable ends together or to connect the end of the cable to another component of the network. In order to perform electrically, cold shrink accessories must be able to withstand the electrical stress that is developed when the cable geometry changes. Cold shrink joints and terminations are pre-fabricated products, meaning that all necessary components are placed into the product during injection molding. These pre-fabricated products are then expanded onto a support that ensures easy installation and limits installation errors.

Master´s thesis topic was to study the possibility to use the same LSR in both underground cold shrink cable terminations and joints. In other words, it was investigated the possibility of using Material 2 instead of Material 1 to reduce waste material, but also to improve productivity and economic benefit. The topic was approached using both basic research and experimental research methods. Aim of the basic research was to increase understanding and knowledge of a subject. Experimental research, on the other hand, involved conducting controlled experiments to observe and analyze cause-and-effect relationships. Quantitative research was employed in the study to collect and analyze of numeric data. Deductive reasoning was utilized in the thesis to draw logical conclusions from general principles or theories.

LSR is widely employed in injection molding for the production of cold shrink accessories, thanks to its remarkable material and processing properties. Both cold shrink joint and cold shrink termination have own grade of material specially tailored for its intended purpose. Considering that cold shrink joints are typically buried underground, they do not necessitate the same level of tracking resistance as cold shrink terminations. Achieving tracking resistance involves incorporating different fillers and additives, which also impact other material properties. As a result, the chemistry of LSR slightly varies between Material 1 and Material 2. When considering material substitution, it is important to evaluate various factors such as the technical performance of the materials, but also the economic advantages and the environmental and legislative aspects.

After conducting the material pre-study, visual inspection and shrinkage test after support removal, standardized mechanical and electrical tests were performed according to laboratory's internal instructions. The visual inspection confirmed that the support can withstand the pressure caused by stiffer silicone since none of the supports were collapsed. Material 2 exhibited slightly better shrinkage than Material 1. The insulating properties of both materials were quite similar.

Since shrinkage of injection molded part is the sum of many factors, material, molding pressure, vulcanization temperature and the mold itself (Bont et al., 2021). It is important to note that the results obtained in this study are limited to the specific conditions and parameters used in the experiments. Further studies are needed to optimize the liquid injection molding parameters for Material 2 and to investigate its performance in shrinkage of molded part.

Electrical test for final product have confirmed that Material 2 meets the required electrical performance standards and exhibits the necessary properties for effective use in cold shrink joints. Therefore, it can be considered a reliable and appropriate material choice for the intended application even though full type test is needed after the molding process parameters are validated.

As a next step, it would be beneficial to develop a control plan, the documented framework that outlines the steps and measures to be implemented for the material substitution process. This is necessary in order to maintain and control the quality of the process and the product.

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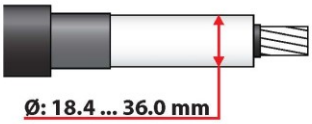
CJH11.2403C Installation Instruction

ENSTO

PEM-CJH11_2403C
2022-09-01
Revision E

CJH11.2403C

$U_o/U\ (U_m)$ kV	mm²
12.7/22 (24) kV	70–240
6.35/11 (12) kV	95–240



2/16 **PEM-CJH11_2403C** **Revision E** 2022-09-01

(CZE) PRÁVNÍ UPOZORNĚNÍ
- Montáž výrobku smí provádět pouze k tomu způsobilá osoba s odpovídajícím proškolením, praxí a s dostatečnými znalostmi bezpečnosti a postupů instalace ve vztahu k elektrickým zařízením. Pokud místní legislativa stanoví požadavky vztahující se k takovému proškolení nebo požadovaným znalostem ohledně montáže elektrického zařízení, musí výše uvedená osoba tyto požadavky splňovat.
- ENSTO nepřebírá žádnou odpovědnost ve vztahu k nárokům vyplývajícím z nesprávného použití nebo nesprávné montáže, anebo nerespektování národních předpisů bezpečnosti výrobků či jiných národních předpisů.
- UPOZORNĚNÍ: Nedodržení instrukce k montáži může mít za následek poškození výrobku nebo i vážné či smrtelné zranění.

(DAN) VIGTIG INFORMATION
- Dette produkt må kun installeres af personer med tilstrækkelig kundskab og uddannelse indenfor installationsarbejde samt sikkerheds- og arbejdsrutiner i forbindelse med elektrisk udstyr. Såfremt lokal lovgivning omfatter bestemmelser eller anbefalinger for uddannelse eller tilstrækkelig viden vedrørende installation af elektrisk udstyr, skal sådanne bestemmelser opfyldes af disse personer.
- Ensto accepterer intet erstatningsansvar i forbindelse med forkert anvendelse, fejlagtig installation af produkter eller manglende overholdelse af nationale sikkerhedsforskrifter eller øvrige bestemmelser.
- ADVARSEL: Forsømmelighed i at følge instruktionen kan resultere i skade på produktet eller i værste fald alvorlig eller fatal personskade.

(ENG) LEGAL NOTICE
- The product must be installed only by a competent person with sufficient training in installation practices and with sufficient knowledge of good safety and installation practices in respect of electrical equipment. If local legislation contains provisions in respect of such training or sufficient knowledge in respect of installation of electrical equipment such provisions shall be fulfilled by the said person.
- Ensto accepts no liability concerning claims resulting from misuse, incorrect installation or ignored national safety regulations or other national provisions.
- WARNING: Failure to follow the installation instructions may result in damage to the product and serious or fatal injury.

(EST) JURIIDILINE MÄRKUS
- Seda toodet tohib paigaldada ainult pädev, paigaldustöödes piisavat väljaõpet omav isik, kellel on piisavad teadmised elektriseadmete turva- ja paigaldustavadest. Kui kohalik seadusandlus või võrguettevõtja kehtestatud eeskiri sisaldab nõudeid niisuguse väljaõppe või elektriseadmete paigaldamiseks piisavate teadmiste kohta, peab paigaldaja neile nõudmistele vastama.
- Ensto ei vastuta nõuete eest, mis tulenevad väärkasutusest, ebaõigest paigaldusest või kehtivate turva- või muude reeglite eiramisest
- HOIATUS: paigaldusjuhiste järgimata jätmine võib kaasa tuua toote kahjustumise ja tõsise või surmava vigastuse.

(FIN) OIKEUDELLINEN ILMOITUS
- Tuotteen asennuksen saa suorittaa vain ammattitaitoinen henkilö, jolla on riittävät tiedot sähkölaitteiden asentamisesta ja sähköturvallisuudesta. Asennus tulee suorittaa voimassa olevia säädöksiä noudattaen. Lisäksi asennuksen suorittajan tulee täyttää kansallisen lainsäädännön asettamat pätevyysvaatimukset.
- Ensto ei vastaa vioista, jotka aiheutuvat tuotteen virheellisestä käytöstä, väärästä asennustavasta tai kansallisten turvallisuusmääräysten noudattamatta jättämisestä.
- VAROITUS! Asennusohjeiden vastainen asennus voi johtaa tuotteen vahingoittumiseen tai vakavaan onnettomuuteen.

(FRA) MENTIONS LÉGALES
- Seules des personnes formées et habilitées aux travaux sous tension BT peuvent mettre en oeuvre ce matériel sur un réseau sous tension. Le port des EPI adaptés et le respect des Conditions d'Exécution du Travail sous tension BT est de la responsabilité de l'opérateur. Le non-respect des instructions d'installation peut provoquer un endommagement du produit et des blessures graves, voire mortelles.
- Ensto n'assume aucune responsabilité quant à des réclamations découlant d'une mauvaise utilisation, d'une installation incorrecte ou d'une méconnaissance des règlements nationaux de sécurité..

(GER) RECHTLICHER HINWEIS
- Das Produkt darf nur von kompetenten und entsprechend geschulten Fachleuten installiert werden, die über ausreichende Kenntnisse im Arbeitsschutz und in der Elektroinstallation verfügen. Wenn das lokale Recht Bestimmungen hinsichtlich der Schulungen und Kenntnisse bei Elektroinstallation enthält, muss die entsprechende Person diese Bestimmungen erfüllen.
- Ensto übernimmt keine Haftung für Ansprüche, die auf Fehlgebrauch, fehlerhafte Montage oder die Nichtbeachtung nationaler Sicherheitsvorschriften oder anderer nationaler Bestimmungen zurückzuführen sind.
- ACHTUNG: Die Nichteinhaltung der Montageanweisungen kann Produktschäden und schwere oder sogar tödliche Verletzungen zur Folge haben.

(HUN) JOGI NYILATKOZAT
- Ezt a terméket csak olyan szakember szerelheti, aki részt vett a megfelelő elméleti, gyakorlati és biztonságtechnikai oktatáson, hálózatépítő szerlői tanfolyamon. Amennyiben a helyi szabályok megkövetelnek további képzettséget vagy szakmai tudást, úgy a szerelést végzőnek a fentieken túlmenően ezeknek is meg kell felelnie.
- Az Ensto nem vállal felelősséget a nem rendeltetésszerű használatból, helytelen vagy nem szakszerű szerelésből, az esetleges nemzeti biztonsági előírások figyelmen kivül hagyásából eredő károkért és következményekért.
- FIGYELEM: a szerelési utasítások megsértése a termék sérüléséhez vezethet, illetve súlyos vagy végzetes sérülést okozhat!

(ITA) NOTE LEGALI
- Il prodotto deve essere installato esclusivamente da persona competente con sufficiente formazione nelle pratiche di installazione e con sufficiente conoscenza delle norme di sicurezza e delle procedure di installazione per le apparecchiature elettriche. Qualora la legislazione locale preveda disposizioni relativamente a tale formazione o sufficiente conoscenza per quanto riguarda la installazione di apparecchiature elettriche, tali disposizioni dovranno essere adempiute da detta persona.
- Ensto non accetta nessuna responsabilità riguardo eventuali danni derivanti da uso improprio, installazione non corretta o che non rispetti le norme di sicurezza o altre disposizioni nazionali.
- ATTENZIONE: La non osservanza delle istruzioni per l'installazione puó causare danni al prodotto e lesioni gravi o fatali.

(LAT) ATRUNA
- Produktu drīkst uzstādīt tikai attiecīgi kvalificēta persona, kura ir pietiekami labi apmācīta veikt šādu uzstādīšanu un kura ir pietiekami zinoša par drošības tehnikas noteikumiem un uzstādīšanas kārtību darbā ar elektroierīcēm. Ja nacionālie normatīvie akti paredz prasības vai īpašus noteikumus attiecībā uz šādu apmācību vai nepieciešamajām zināšanām darbā ar elektroierīcēm, tad minētajai personai šīs prasības un noteikumi ir jāievēro.
- Ensto neuzņemas nekādu atbildību par prasījumiem, kas cēlušies no nepareizas lietošanas, nepareizas uzstādīšanas, nacionālo drošības noteikumu vai citu noteikumu neievērošanas.
- UZMANĪBU: Uzstādīšanas instrukciju neievērošana var radīt kaitējumu produktam vai radīt smagus vai nāvējošus ievainojumus.

(LIT) TEISINIS PRANEŠIMAS
- Gaminį gali montuoti tik apmokytas asmuo, turintis vietos reikalavimus atitinkančią kvalifikaciją. Jei vietos įstatymai reikalauja - asmuo turi būti baigęs praktinius gaminio montavimo mokymų kursus.
- Ensto neatsako už atsitiktinę, netiesioginę ar pasekmių žalą, kurią padaro šio gaminio netinkamas panaudojimas, neteisingas montavimas, saugos ar kitų nacionalinių reikalavimų nepaisymas.
- DĖMESIO! Šios montavimo instrukcijos nurodymų nepaisymas gali sugadinti gaminį bei sukelti rimtą ar net mirtiną traumą.

(NOR) JURIDISK INFORMASJON
- Produktet må bare installeres av en kompetent person med tilstrekkelig opplæring i praktisk montasje og med tilstrekkelig kunnskap om sikkerhet og installasjonspraksis i forhold til elektrisk utstyr. Hvis lokal lovgivning inneholder bestemmelser om slik opplæring, eller om å inneha tilstrekkelig kunnskap i installasjon av elektrisk utstyr, skal slike bestemmelser oppfylles av vedkommende som utfører montasjen.
- Ensto tar ikke noe ansvar vedrørende krav som følge av feil bruk, feil installasjon eller ignorerte nasjonale sikkerhetsforskrifter eller andre nasjonale bestemmelser.
- Advarsel: Unnlatelse av å følge installasjonsinstruksjonene kan resultere i skade på produktet og føre til alvorlige eller dødelige personskader.

(POL) POUCZENIE
- Produkt powinien zostać zainstalowany przez wykwalifikowaną osobę, posiadającą stosowne doświadczenie i wiedzę w zakresie zasad bezpieczeństwa oraz instalacji sprzętu elektrycznego. O ile miejscowe przepisy zawierają postanowienia dotyczące wymogu posiadania doświadczenia, bądź niezbędnej wiedzy w zakresie instalacji urządzeń elektrycznych, postanowienia te powinny zostać wypełnione przez wspomnianą powyżej osobę.
- Ensto nie ponosi żadnej odpowiedzialności za niewłaściwe korzystanie, nieprawidłową instalację lub naruszenie regulacji krajowych dotyczących bezpieczeństwa, bądź innych krajowych przepisów prawnych;
- OSTRZEŻENIE : wykonanie instalacji w sposób niezgodny z instrukcją może skutkować uszkodzeniem produktu i poważnymi lub śmiertelnymi obrażeniami ciała.

(POR) AVISO LEGAL
- Este acessório só deverá ser instalado por pessoal especializado, com suficiente formação neste tipo de trabalho, familiarizado com equipamentos eléctricos e aplicação das regras de segurança. Se a legislação local exigir formação ou treino adicional, é da responsabilidade do operador cumprir esses requisitos.
- A Ensto e a RESUL não assumem responsabilidades relativas a reclamações originadas por mau uso, instalação incorrecta ou desconhecimento de regulamentos de segurança ou outra legislação.
- AVISO: A falha em seguir as instruções de montagem pode resultar em danos no acessório e ferimentos graves ou fatais.

(RON) AVIZ JURIDIC
- Produsul trebuie instalat numai de către o persoană competentă, cu pregătire suficientă în practicile de instalare și cu cunoștințe suficiente de bune în practici de siguranță și de instalare în ceea ce privește echipamentele electrice. În cazul în care legislația locală conține dispoziții cu privire la o astfel de formare sau cunoștințe suficiente în ceea ce privește instalarea de echipamente electrice, aceste dispoziții vor fi îndeplinite de către persoana respectivă.
- Ensto nu își asumă nici o responsabilitate în ceea ce privește reclamațiile rezultate din utilizarea necorespunzătoare, instalarea incorectă sau ignorarea reglementărilor naționale de siguranță sau a altor dispoziții naționale.
- AVERTIZARE: Nerespectarea instrucțiunilor de instalare poate duce la deteriorarea produsului și accidente grave sau mortale.

(RUS) ПРАВОВОЕ УВЕДОМЛЕНИЕ
- Изделие должно быть установлено только компетентным человеком, имеющим соответствующую профессиональную подготовку и знающим технику безопасности. Если местное законодательство требует сдачи соответствующих нормативов и прохождения курсов подготовки для допуска к работе, то эти условия должны подлежать обязательному персональному выполнению.
- Ensto не несет ответственность за последствия при неправильном использовании, установке или игнорировании правил техники безопасности или других местных положений.
- ПРЕДУПРЕЖДЕНИЕ: Несоблюдение инструкций по установке может привести к повреждению изделия и к серьезной или даже фатальной травме.

(SLK) PRÁVNA STRÁNKA MONTÁŽE
- Montáž výrobku smie vykonávať len kompetentná osoba s adekvátnym tréningom, praxou a s dostatočnými znalosťami bezpečnosti práce vzhľadom k príslušnému vybaveniu elektrického zariadenia a priestorom. Ak miestna legislatíva obsahuje nariadenie takých tréningov alebo požiadaviek na dostatočné vedomosti s ohľadom na inštalácie týkajúci sa elektrického zariadenia, tak tieto opatrenia budú vykonávané u tejto osoby.
- ENSTO neakceptuje žiadnu zodpovednosť týkajúcej sa nárokov vyplývajúcich z nesprávneho použitia, nesprávnej montáže alebo ignorovania národných bezpečnostných pravidiel alebo iných národných nariadení.
- UPOZORNĚNÍ: Nedodržanie postupu montážneho návodu môže mať za následok poškodenia výrobku alebo i vážne zranenia.

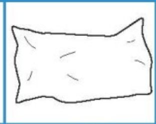
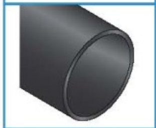
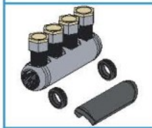
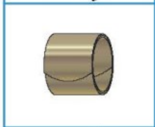
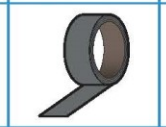
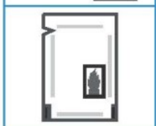
(SLV) PRAVNO OBVESTILO
- Proizvod lahko vgradi le strokovno usposobljena in pooblaščena oseba z zadostnim znanjem v procesih vgradnje, varstvu pri delu in montaži električne opreme. Če lokalna zakonodaja vsebuje določbe v zvezi s takšnim usposabljanjem in zadostnim znanjem vgradnje električne opreme morajo biti te določbe izpolnjene s strani omenjene osebe.
- Podjetje Ensto ne prevzema nobenih odgovornosti v zvezi z zahtevki, ki so posledica napačne uporabe, nepravilne vgradnje ali zanemarjanja nacionalnih varnostnih predpisov in drugih določb.
- OPOZORILO: Neupoštevanje navodil za namestitev lahko povzroči poškodbe izdelka in posledično nevarnost resnih telesnih ali smrtnih poškodb.

(SPA) AVISOS LEGALES
- El producto debe ser instalado sólo por una persona competente con capacitación suficiente en prácticas de instalación y con conocimiento suficiente de las normativas de seguridad adecuadas con respecto al equipamiento eléctrico. Si la legislación local contiene disposiciones con respecto a dicha capacitación o conocimiento suficiente con respecto a la instalación del equipo eléctrico dicha persona deberá cumplir con tales disposiciones.
- Ensto no acepta ninguna responsabilidad con respecto a los reclamos que resultan del uso indebido, instalación incorrecta o regulaciones de seguridad nacional ignoradas u otras disposiciones nacionales.
- ADVERTENCIA: No seguir las instrucciones de instalación podría resultar en un daño al producto y lesión grave o fatal.

(SWE) VIKTIG INFORMATION
- Denna produkt får endast installeras av person med erforderlig kunskap och utbildning avseende installationsarbete och säkerhets- och installationsfrågor beträffande elektrisk utrustning. Om tillämplig lagstiftning eller gällande föreskrifter innehåller bestämmelser eller rekommendationer beträffande sådan kunskap och utbildning eller behörighetskrav med avseende på installation av elektrisk utrustning skall vad som härvid föreskrivs tillämpas med avseende på den som utför installationen. Vid tveksamhet om vad som gäller kontrollera med fackkunskap.
- Ensto friskriver sig från allt ansvar beträffande krav i anledning av felaktig användning eller felaktig installation av produkten eller underlåtenhet att iaktta lokala säkerhetsföreskrifter eller andra tillämpliga bestämmelser eller rekommendationer.
- VARNING: underlåtenhet att följa instruktionerna avseende installation kan resultera i skada på produkten och även allvarlig skada på person eller dödsfall.

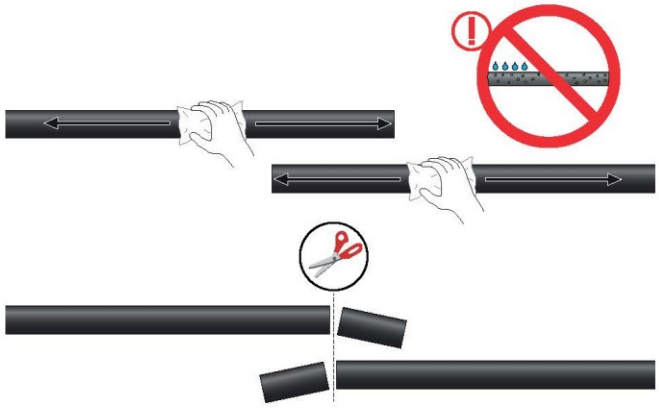
ENSTO FINLAND OY ENSIO MIETTISEN KATU 2, P.O.BOX 77 06101 PORVOO, FINLAND TEL. +358 204 76 21 EMAIL: ENSTO@ENSTO.COM WWW.ENSTO.COM

2022-09-01 **Revision E** **PEM-CJH11_2403C** 3/16

	CSJM16-45/340-50L	1		PA23	1
	CPEEPL68-19 675 mm	1		PEE64.1 600 mm	1
	CA240SB4	1		PEE64 150 mm	1
	SF3	2		PEE225W	1
	PEE226/580	1		PEM-CJH11_2403C	1
	ALT75/140	1			
	SACTA20.2	2			
	SMG200	2			
	SSATA10	2			
	RFL15 MPA21	1 1			
	CT149	2			

4/16 **PEM-CJH11_2403C** **Revision E** 2022-09-01

1



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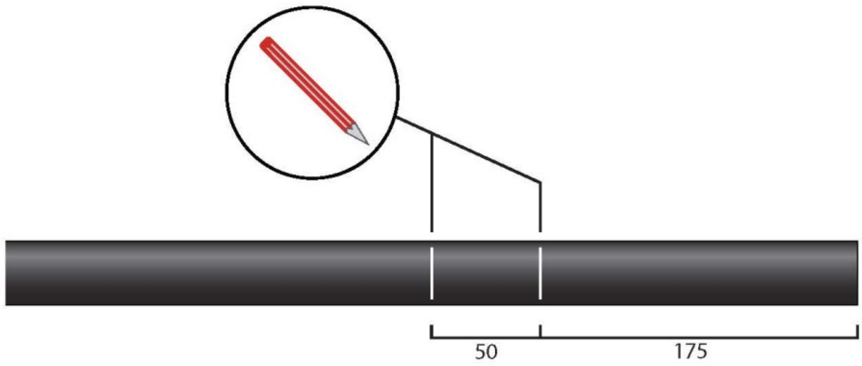

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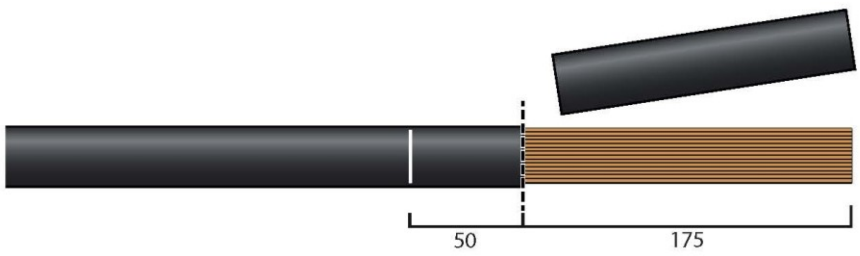
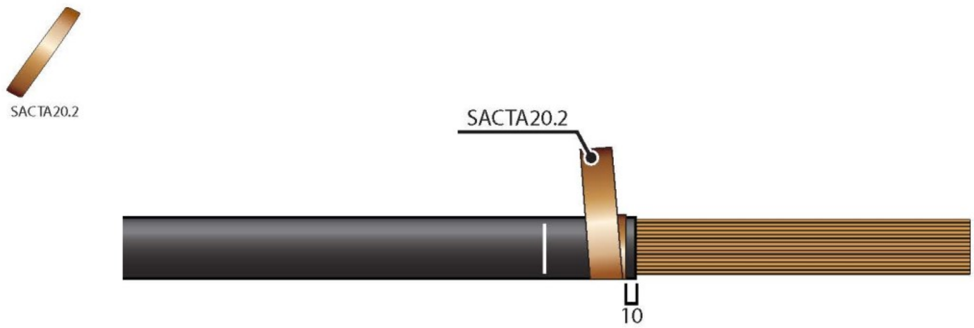


2022-09-01 **Revision E** **PEM-CJH11_2403C** 5/16

4 ☐



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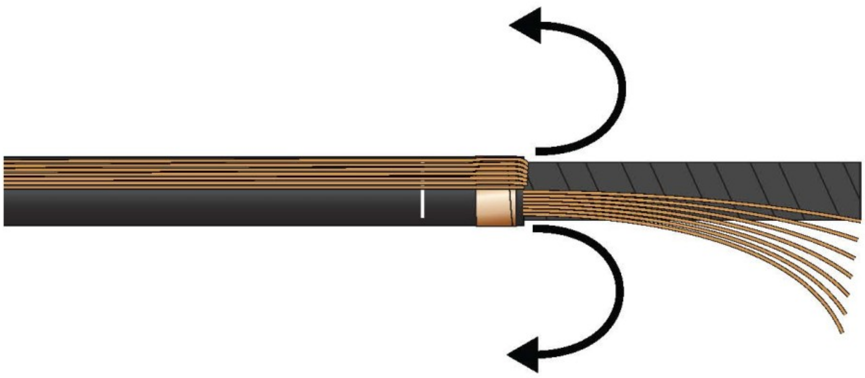

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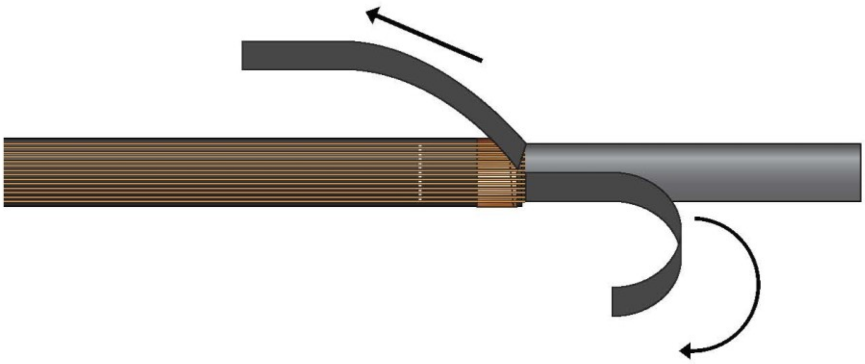

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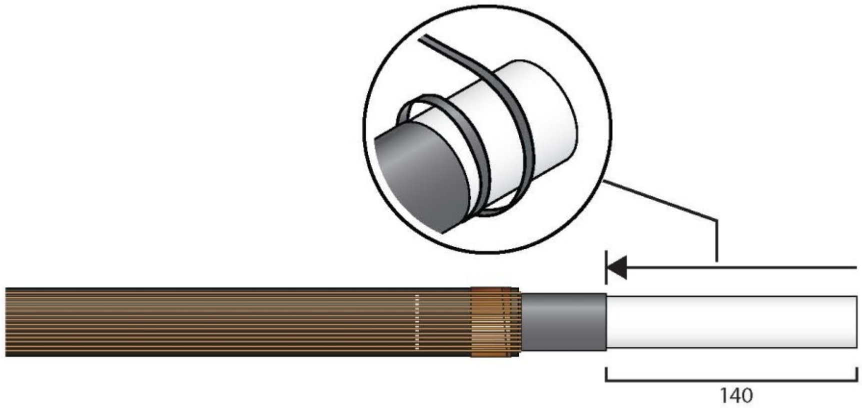

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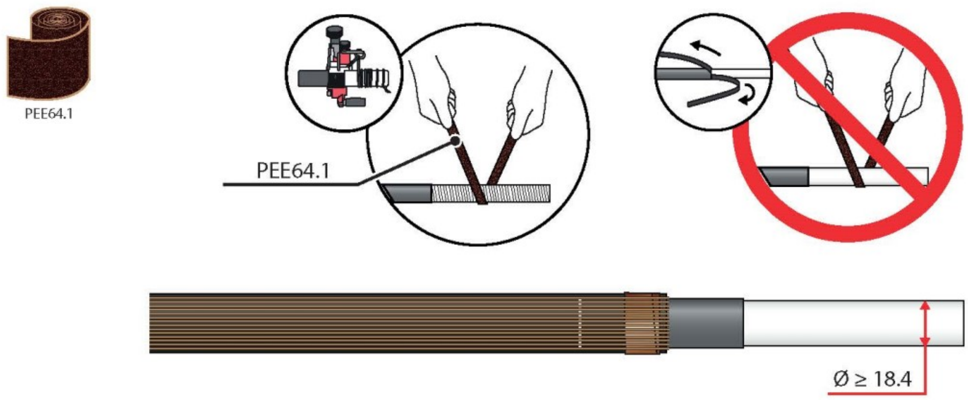

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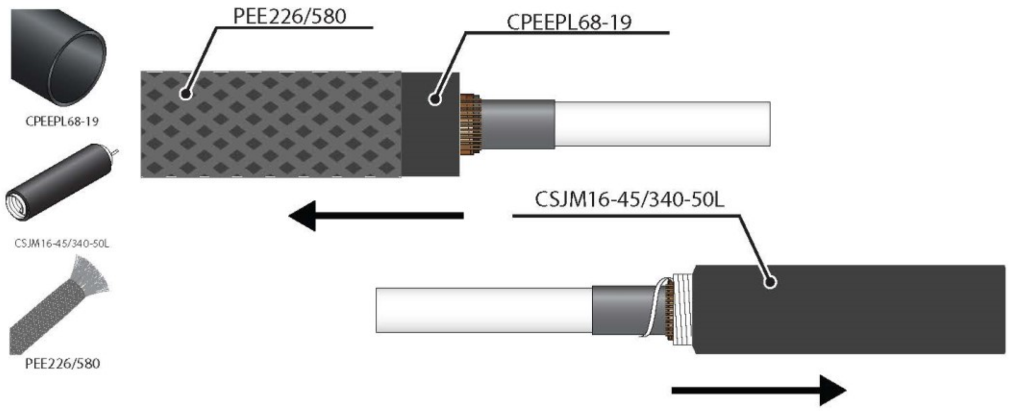
2022-09-01 **Revision E** **PEM-CJH11_2403C** 7/16

10 ☐



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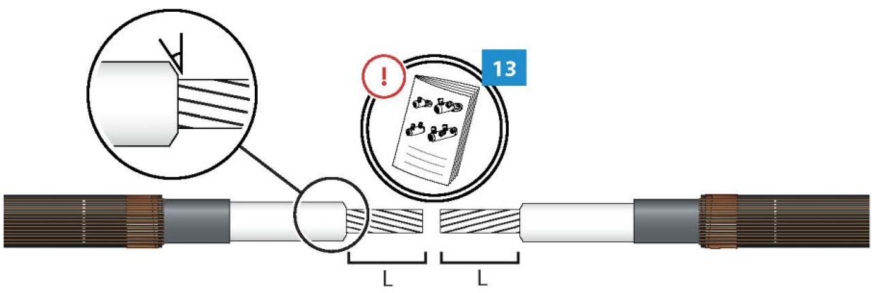

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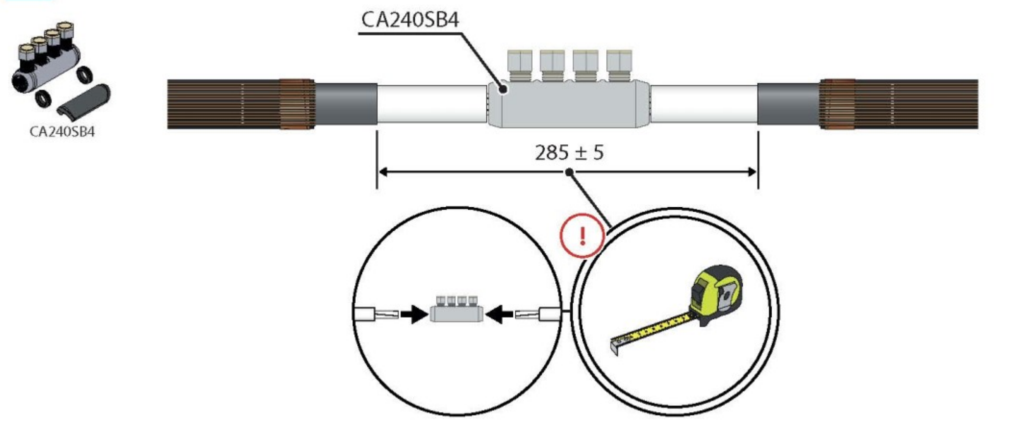

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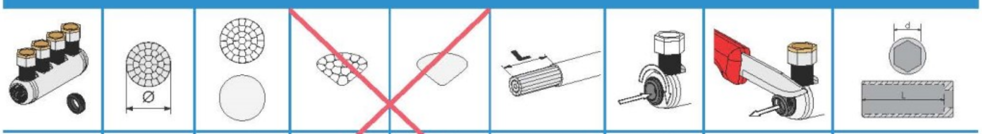
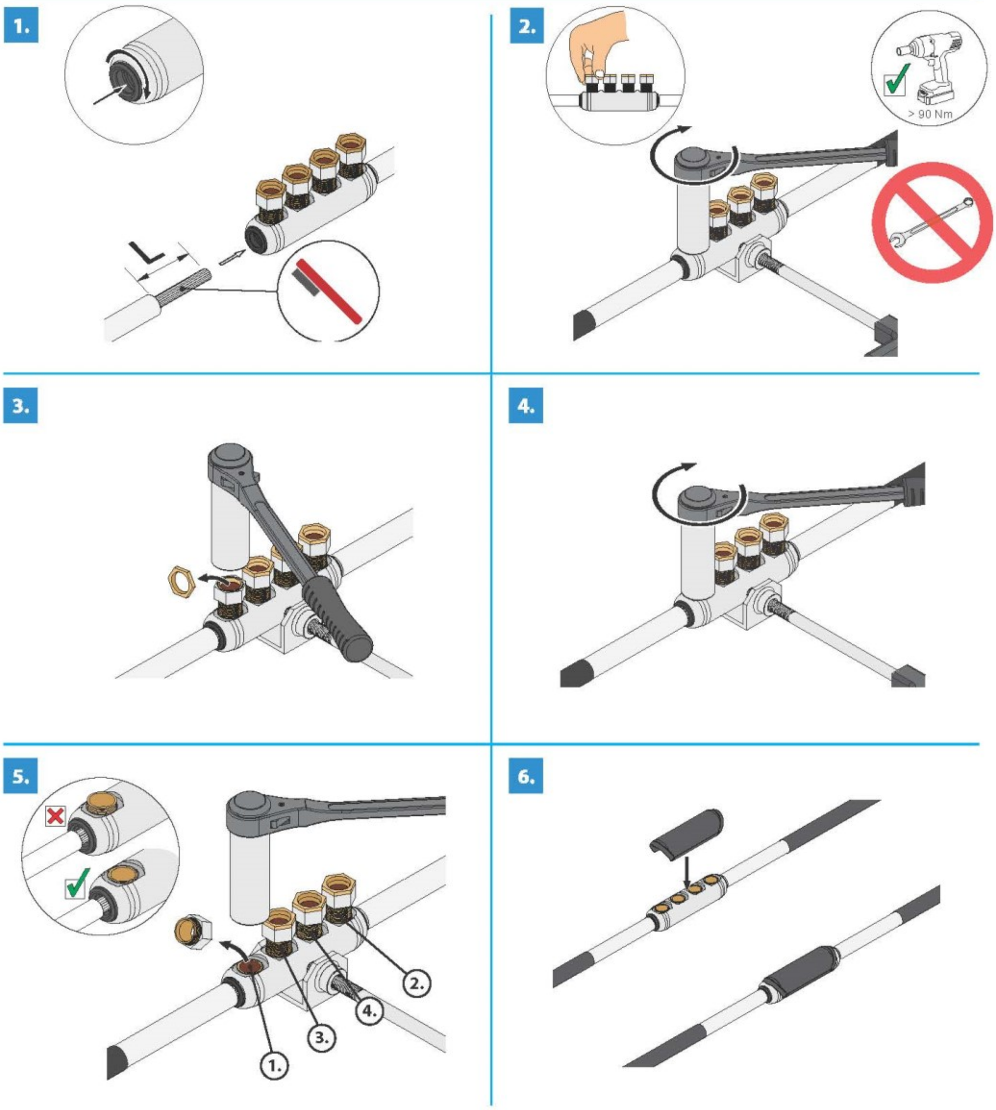


	mm	mm²	mm	mm²	mm	mm²		mm
CA240SB4	7.7-19.2	50-240	90° 50-150 120° 50-120	90° 50-185 120° 50-150	60	50-95	120-150	d = 21 L_{min} = 26



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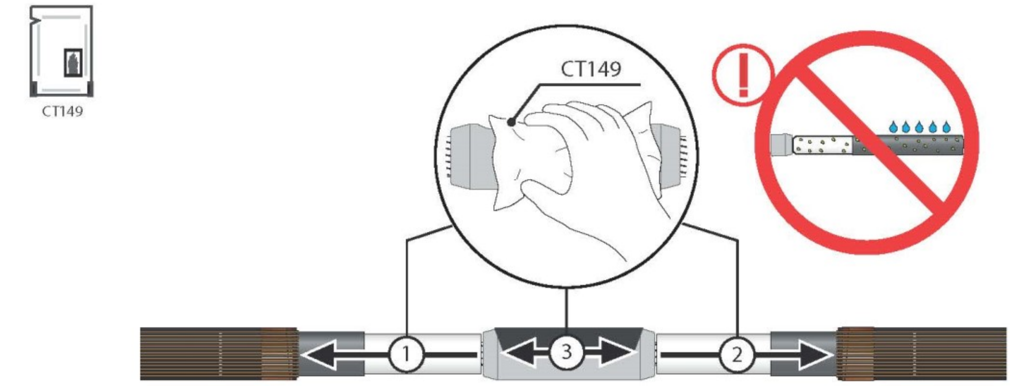

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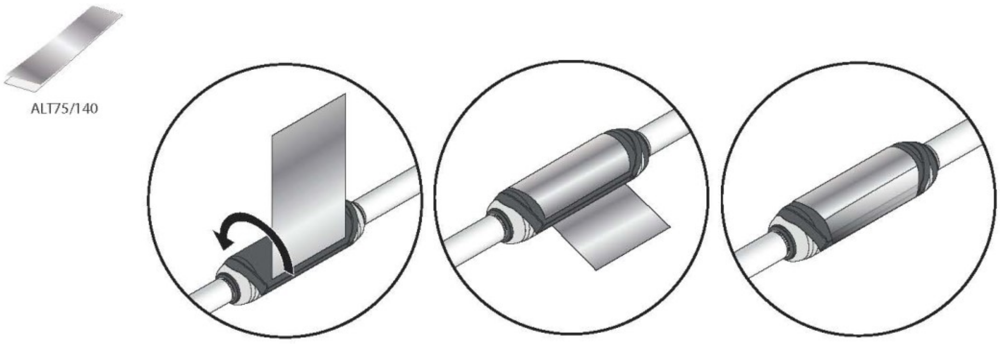

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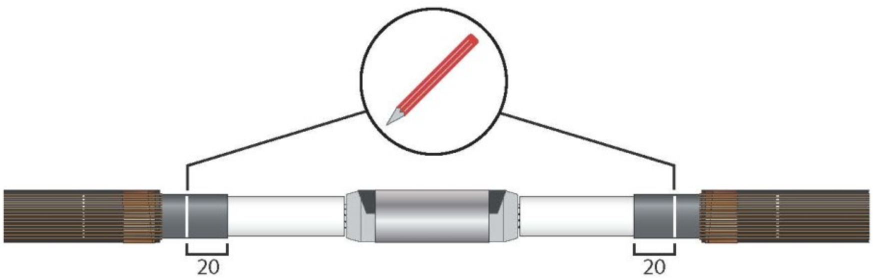
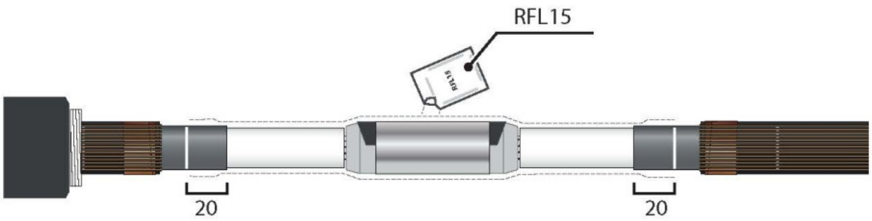


10/16 **PEM-CJH11_2403C** **Revision E** 2022-09-01

17 ☐



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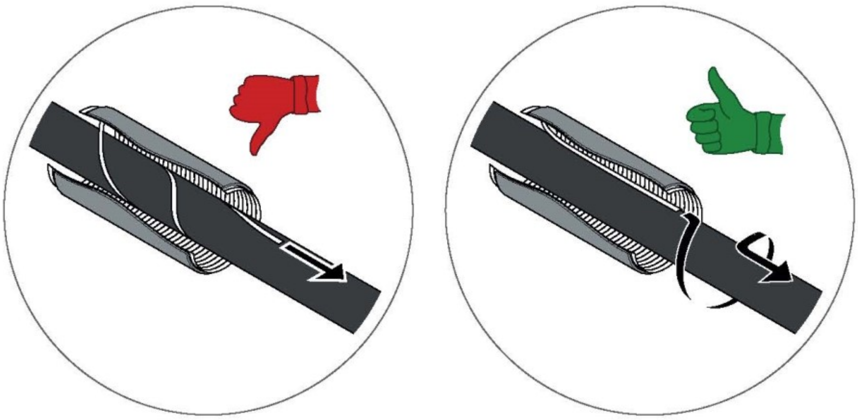
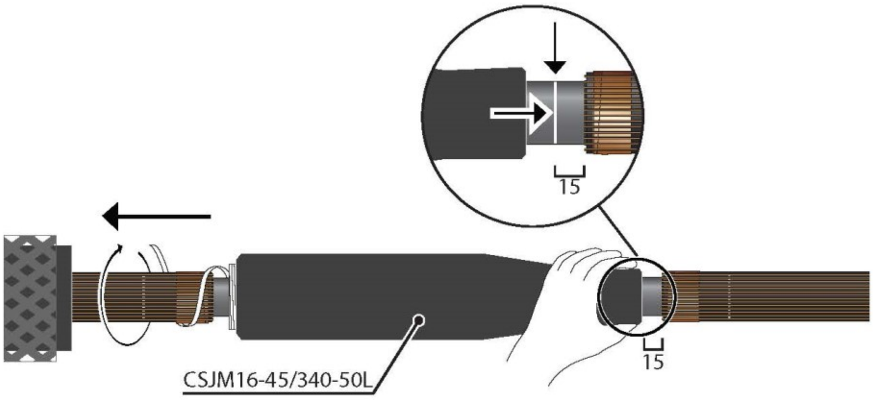
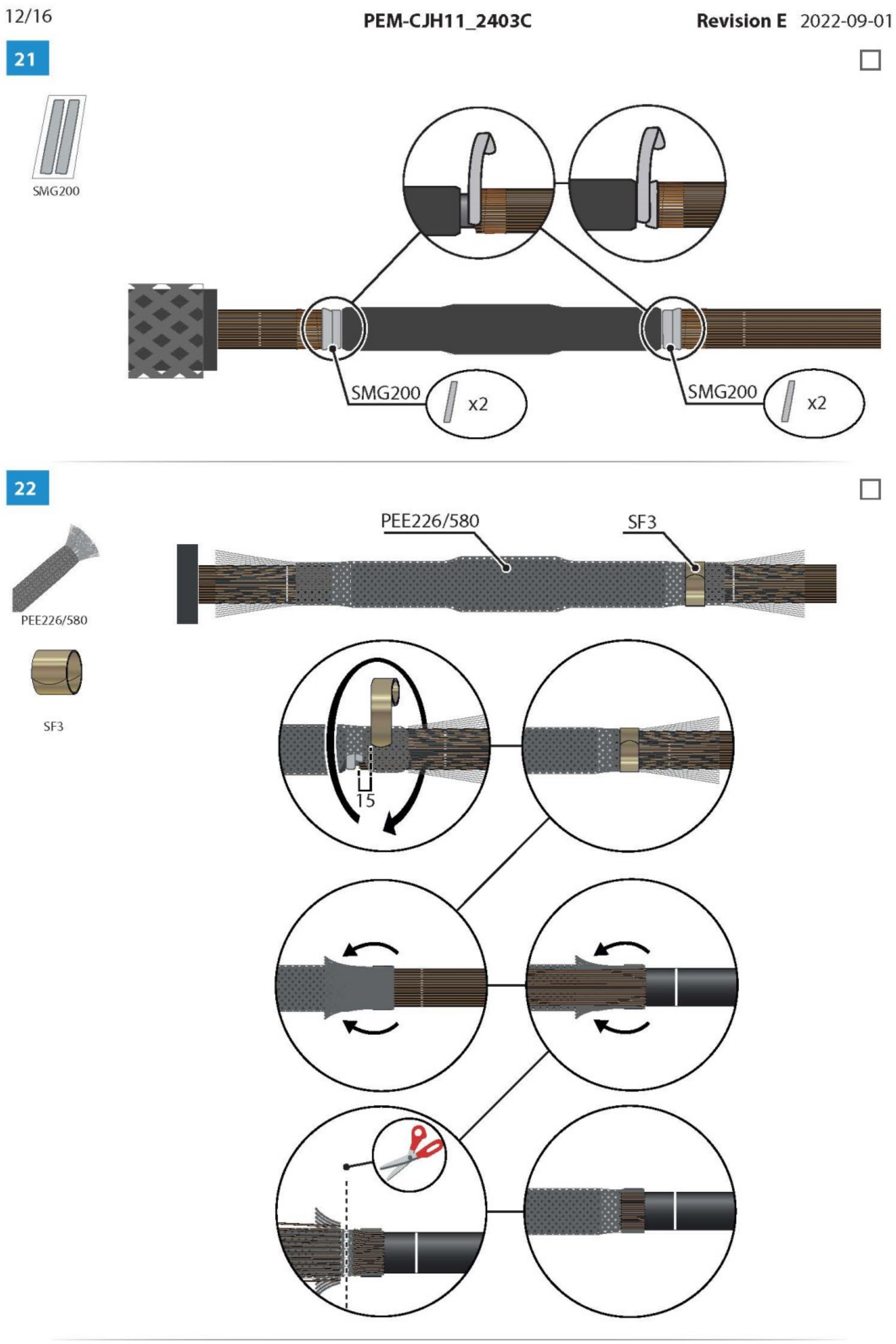


19 ☐



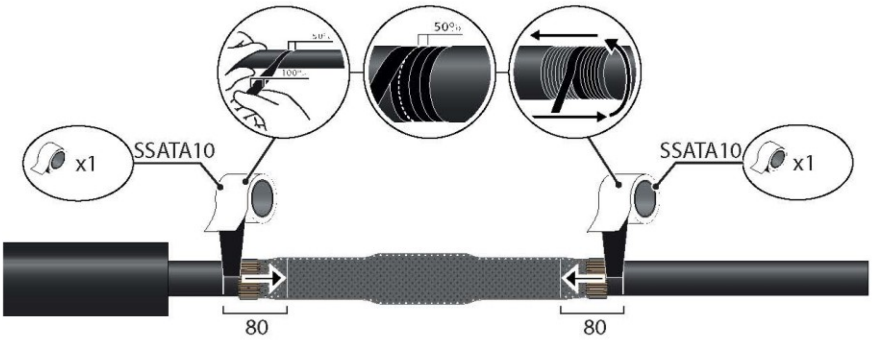
20 ☐


12/16
PEM-CJH11_2403C
Revision E 2022-09-01
21
SMG200
SMG200
x2
SMG200
x2
22
PEE226/580
SF3
PEE226/580
SF3
15

2022-09-01 **Revision E** **PEM-CJH11_2403C** 13/16

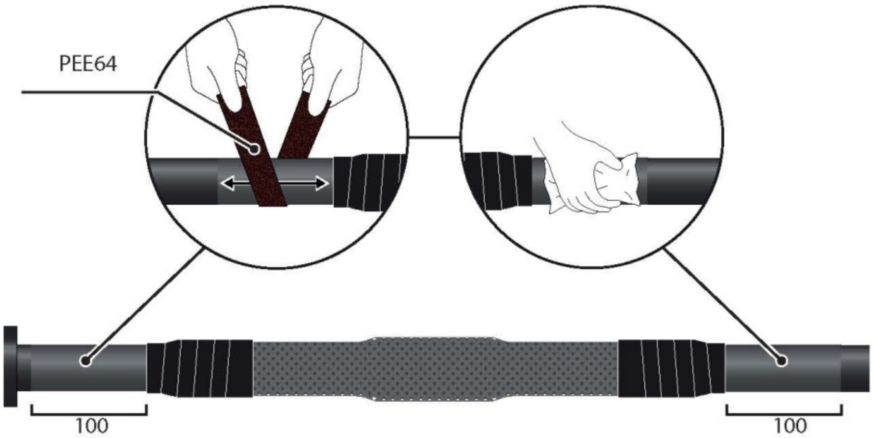
23 ☐

SSATA10



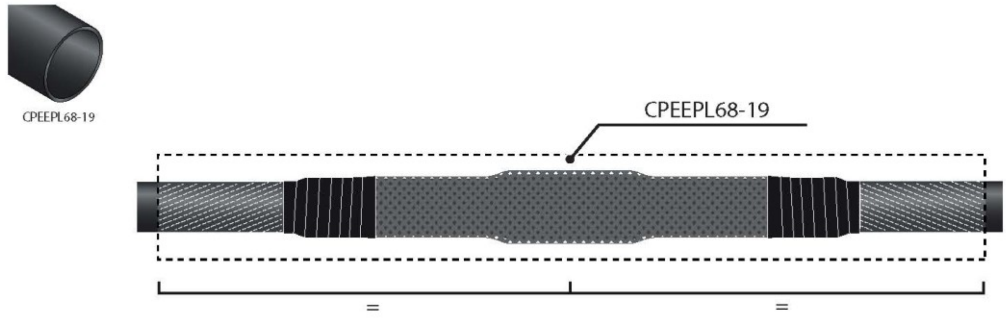
24 ☐

PEE64



14/16 **PEM-CJH11_2403C** **Revision E** 2022-09-01

25



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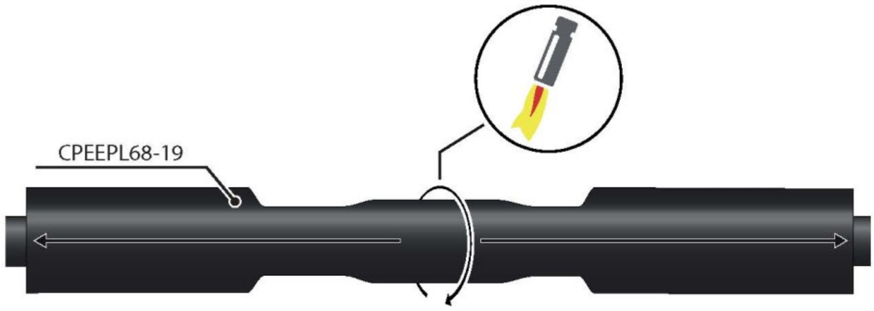

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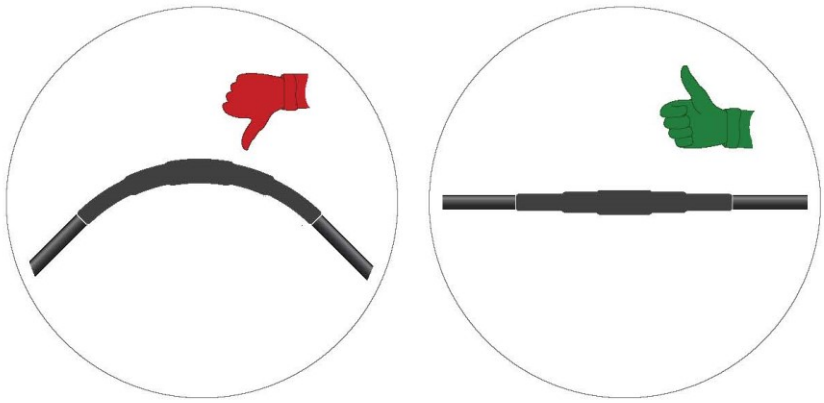

Table 1. Requirements for material properties for insulating silicone rubber used in cold shrink joints.

Material properties	**Test standard:**	**Min**	**Max**
Viscosity [Pas]	DIN 53018 or similar	200	500
Elongation at break [%]	ISO 37 or similar	500	
Tensile strength [MPa]	ISO 37 or similar	5,5	
Hardness, shore A	ISO 7619-1 or similar	28	36
Density [g/cm^3]	ISO 1183 or similar	1,08	1,14
Tear strength [kN/m]	ASTM D 624-B	30	
Volume resistivity [Ωcm]	IEC 60093 or similar	1E+14	
Dielectric strength [kV/mm]	IEC 60243-1 or similar	20	

Table 7. Average test results of Material 1 and Material 2.

Material property	**Min.**	**Max.**	**Material 1. test sheet**	**Material 2. test sheet**	**Material 1. LIM**	**Material 2. LIM**
Viscosity [Pas]	200	500	Not able to test	Not able to test	Not able to test	Not able to test
Elongation at break [%]	500		493	700	543	422
Tensile strength [MPa]	5,5		6,5	15,0	4,9	8,3
Hardness, shore A	28	36	33	36	31	43
Tear strength [kN/m]	30		30	33	31	30
Volume resistivity [Ωcm]	1E+14		5E+15	1E+15	Not tested	Not tested
Dielectric strength [kV/mm]	10		17	20	Not tested	Not tested

Table 8. Average results of volume resistivity and dielectric strength.

Material property	**Min.**	**Max.**	**Material 1. test sheet**	**Material 2. test sheet**	**Material 1. LIM**	**Material 2. LIM**
Volume resistivity [Ωcm]	1E+14		5E+15	1E+15	Not tested	Not tested
Dielectric strength [kV/mm]	10		17	20	Not tested	Not tested

Table 10. Electrical test results.

Test of EN 61442	**Clause**	**Requirement**	**Result**
AC voltage dry	4	5 min at 4,5 Uo, no breakdown nor flashover	Passed
Partial discharge at ambient temperature	7	Max. 10 pC at 2 Uo	Passed
Impulse voltage at elevated temperature	6	10 impulses at each polarity, no breakdown nor flashover	Passed