# Diffusion Behavior of Greases in Interfaces in Organic Insulation Materials

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## Abstract

The diffusion of greases in organic insulation materials, which is the core parameter of the electrical and mechanical long-term behavior of the interface, is studied. The diffusion of grease depends both on the solid organic insulation material and on the grease. The highest diffusion can be observed by the combination of a silicone paste and silicone rubber. However, for silicone rubber there are low and no diffusion lubricants existing. The diffusion in EPDM, EP and XLPE is commonly much lower. In EP and XLPE, no type-dependency of the grease can be observed. With the knowledge of the diffusion behavior, the desired interface properties can be achieved for the whole lifespan of the apparatus.

## 1. Introduction

Greases play a major role in the MV and HV cable connection technology. Their lubrication is needed both for the slip-on procedure as well as for the allowance of thermally driven movement during operation. In contrast to the common use-case of grease in e.g. bearings, the situation in the HV cable accessories technology differs significantly:

1. The solid interface partners are organic materials having both high coefficients of static friction and allowing possibly the diffusion of the grease or some ingredients of it.
2. The static friction is extremely slow and thus dominates the movement during the operation.
3. There is no remixing of the grease components by e.g. the bearing's balls.
4. Longer service life without maintenance in case of HV cable accessories technology compared to e.g. bearing systems.

The second beneficial property of the grease in electrical stressed interfaces is the filling of the surface structure with a material with higher dielectric strength and relative permittivity than air.
As both the mechanical and the electrical properties of the interfaces are usually tested with fresh grease, these measurements are not subject of this paper. Instead the focus is put on the diffusion of different grease types in the relevant organic insulation materials.

## 2. Interface and Grease

In this chapter, both the interface with its parameters and the grease is described.

### 2.1. Interface properties

Technical interfaces are not perfectly smooth. The profile is described with parameters such as the maximum height, the mean height and the profile peak height and depth. Therefore, the contact between two different solid bodies is not extensive but punctiform. Between the contact points there is air. According to Paschen's law the discharge will appear in this area at lower field strengths than it would appear in the solid insulation material. Thus, effort is put in the reduction of the size of the air-filled voids. On the material side, this can be achieved by reducing the surface roughness or increasing the elasticity of at least one contact partner. On the interface side increasing the interface pressure and / or lubricating the interface with grease also reduces both the number and the size of the voids as displayed in **Fig. 1**.

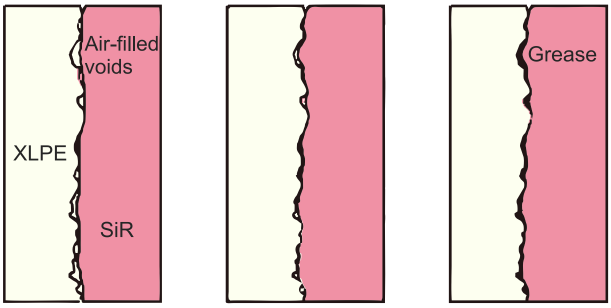


**Fig. 1** – The tribosystem: Interface between silicone rubber and XLPE [1]
Left: Low interface pressure and no grease leads to big air-filled cavities in the interface
Centre: High interface pressure and no grease leads to small air-filled cavities in the interface
Right: High interface pressure leads to small cavities, which are filled with grease

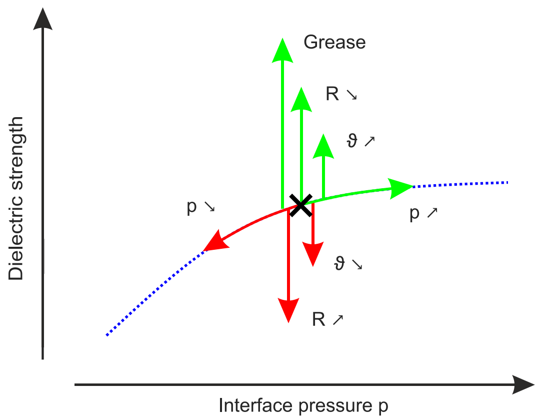


**Fig. 2** – Influence of the surface roughness of the XLPE ("R"), the interface pressure ("p") and the temperature ("ϑ") on the dielectric strength of the interface [1]

Grease is due to its void-filling and lubrication properties the one of the key factors for the electrical strength of interfaces. As it can be seen in **Fig. 2** it has the highest influence on it. Additionally, grease homogizes the interface pressure avoiding both too high interface pressures leading to necking [2] and too low ones resulting in a lower dielectric strength of the interface.

### 2.2. Grease systems

Grease generally consist of two main components: The oil as lubrication and a thickener keeping the oil in the right place. The typical soap-like structure of the thickener is shown in **Fig. 3**.

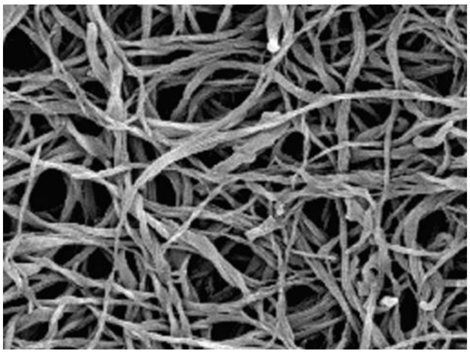

**Fig. 3** – Soap-like structure of the thickener [3]

Grease separates to achieve better lubrication properties [4]. By this, constantly a small amount of oil being capable to creep and lubricate well is available. To achieve the long-term lubrication of electrical interfaces it is thus evident that the oil does not diffuse in the organic insulation materials as the thickener alone cannot provide sufficient mechanical and electrical properties.
In this study two different types of greases are investigated: Silicone-based greases as well as PTFE-based ones. Silicone oil used in the silicone-based greases have a chemical analogy to silicone rubber used as insulation material. PTFE-based grease differs chemically from the organic insulation materials and it shows emergency lubrication properties when blead out.

## 3. Experimental setup

Each diffusion measurement is carried out with six samples of 150 mm * 40 mm. Grease is applied on one side coating an area of 60 cm².
The specimen are stored in closed boxes with two small trays with saturated magnesium chloride hexahydrate solution providing a constant relative humidity of 35 % at 60 °C. The two-layer storage arrangement is shown in **Fig. 4**. Cropped corners of the specimen allow a permanent identification even after multiple cleaning cycles. A two-week preconditioning time in the controlled ambient conditions ends the humidity diffusion.
In the evaluation the mean value and the wingspan of the weight of the six specimen is evaluated. By this, the negative effect of statistical outliers is avoided.

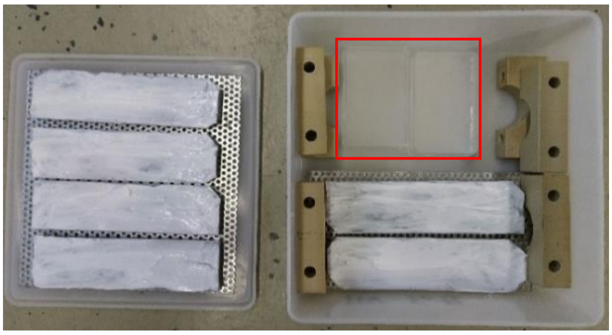

**Fig. 4** – Storage box for a set of six specimen with grease and the saturated salt solution to keep the air humidity constant (red marked in the top of the box)

After that preconditioning, the grease is applied on one side of the specimen and the samples are stored for one week. Then the grease is removed with a spatula followed by a cleaning procedure with alcohol-soaked wipes using isopropanol. In a previous experiment it was checked that there is no significant diffusion of isopropanol during that short period of time in the insulation materials.
After the cleaning and the ventilation time, when the cleaning solvent is evaporated, the specimen are weighted. The median and the wingspan of the specimen weight for the different materials is displayed in **Fig. 5** to **Fig. 10** week by week. After the weighting fresh grease is applied and the specimen are stored again for one week. This cycle is repeated nine weeks resulting in a contact time of more than 1,500 hours.
Every week new grease is applied due to two facts: First, the test is harder as the oil in the grease is weekly refreshed and thus its content is higher than in the real application leading to a faster diffusion and a higher steady state oil concentration in the solid insulation material. Second, handling is easier as always a defined amount of fresh and clean grease is used.

## 4. Experimental results

The diffusion results are presented material-by-material in the following chapter.

### 4.1. Silicone rubber (SiR)

The median and the wingspan of the normalized specimen weight for the four different greases is displayed in **Fig. 5**. Grease A leads to a very small specimen weight increase in the sub-permille range. Repeated application of grease B has no measurable influence of the specimen weight. The wingspan of the results of these two PFTE-based greases are small, too. For grease C, there is a remarkable increase of the median of the specimen weight during the nine weeks. The wingspan are still comparatively small and there is a saturation effect visible even if there is fresh grease applied weekly. After nine weeks, the median of the specimen weight is increased by about 2.5 %. Applying grease D leads to both the highest weight increase of nearly 6 % in nine weeks as well as to the highest wingspan. During the measurement period, there is no clear saturation visible and the course of the median of the specimen weight point to an even higher weight increase in case of an elongated contact with permanently refreshed grease.

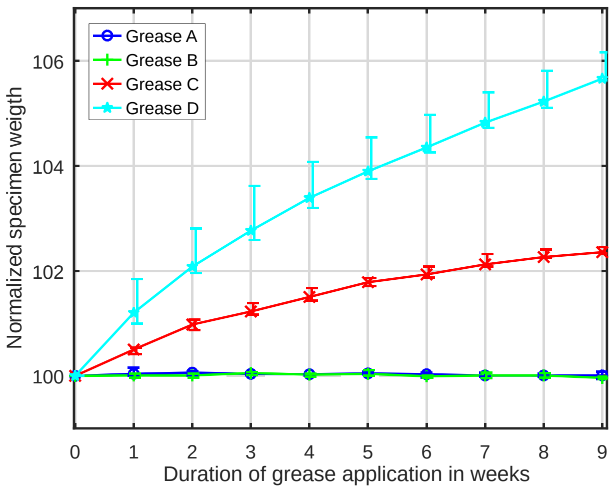


**Fig. 5** – Diffusion result of four different greases in SiR without pressure

Grease A and grease B are PTFE-based greases whereas grease C and D are silicone-based ones. In **Fig. 6** grease D is left out to get a impression of the diffusion behaviour of the other greases and better comparison for the up-coming material pairings.

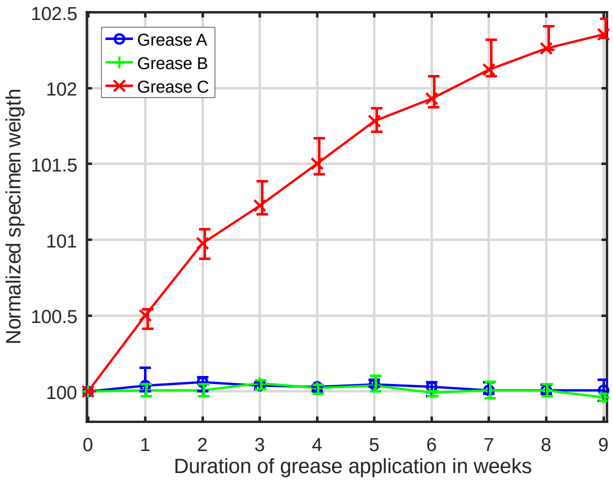


**Fig. 6** – Detailed diffusion result of three different greases in SiR without pressure

SiR is elastic and can thus be expanded during the slip-on procedure resulting in an interface pressure. By this, the void size is reduced as shown in **Fig. 1** and so the electric breakdown strength increases as shown in **Fig. 2**. This deformation however results in an internal mechanical stress of the insulation material and thus the diffusion of the greases A, B and C is examined under an interface pressure of about five bar relative.
The median of the specimen weight of grease A achieves its peak value of about 3 ‰ after four weeks. Finally, the median is about 1 ‰ lower than it was at the beginning. As the wingspan still crosses the 100 %-line, there might be no weight reduction compared with the starting weight. Grease B shows a similar behavior with less than half the weight increase in the first half of the experiment and with a nearly constant median of the specimen weight in the second half. Grease C, the only silicone based grease, increases the median of the specimen weight by 1.4 % during the nine weeks. Compared to the results achieved with SiR specimen without interface pressure, the wingspan in all three cases are higher.

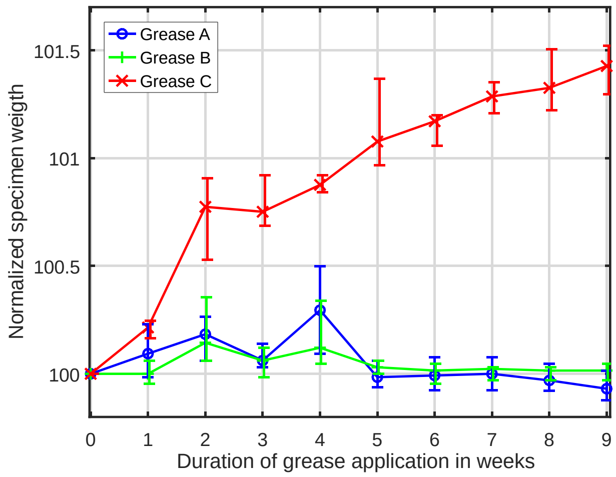


**Fig. 7** – Diffusion result of three different greases in SiR with interface pressure of about 5 bar

The pressurized grease adhering better on the specimen surface can explain the higher wingspans. This makes cleaning more difficult and thus the wingspan bigger. Especially in cases where the median differs from the long-term expectation the wingspan is big and mostly covers the long-term expected value. For the PTFE-based greases A and B, there is no significant pressure-dependency measureable. However, in case of grease C a lower diffusion can be seen. Assuming that the diffusion proceeds pressure-independent at the same rate it is reduced by about 40 % due to the interface pressure up to 5 bar.

## 4.2. Ethylene propylene diene monomer rubber (EPDM)

Two different EPDM mixtures are examined both with grease A and C. The different EPDM mixtures 1 and 2 are represented with solid and a dotted lines in **Fig. 8**. Generally, there is a slightly decreasing median of the specimen weight in case of the application of grease A and an increasing one in case of grease C. EPDM 1 shows a higher weight decrease and increase than EPDM 2 does. The median of the specimen weight increase after nine weeks is below 2 ‰ and thus about 10 % the one of SiR. The wingspan is comparatively high, especially in cases when the median differs from the long-term expected values.

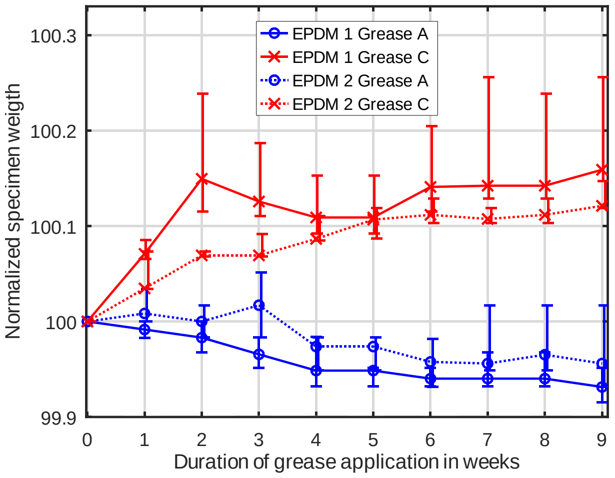


**Fig. 8** – Diffusion result of two different greases in two different EPDM rubbers without pressure

The weight decrease due to the application of grease A might come from a washing-out process of some EPDM components. In contrast to this, the usage of grease C results in significant weight increase due to diffusion of grease or some of its ingredients.

The comparatively big wingspan in **Fig. 8** is a result of both the scaling of the abscissa due to the low weight change and the cleaning procedure of the surface with comparatively high coefficient of static friction making a perfect cleaning in a short time hard to achieve. Especially in the use-case of grease C, which is more viscose and thus stickier and harder to clean, the wingspan is increased.

## 4.3. Crosslinked polyethylene (XLPE)

XLPE has a chemical structure differing from all greases with both crystalline and amorphous regions [5]. The latter contain water and some polar cross-linking by-products. In these regions with polar molecules, the charges can be attracted leading to a space charge accu-mulation. The accumulation of charge carriers can be caused by the wiping process during cleaning and can influence the result determined during measureing the weight.

In **Fig. 9** the normalized specimen weight course and the wingspan for the greases A, B and C is displayed. In all three lubrication cases, the median of the specimen weight is both increasing and decreasing during the experiment. At the end, there is no significant weight increase in case of grease B and C. In case of grease A, there is a weight increase of about 1.5 ‰ and the wingspan does not cross the 100 %-line. Due to the charge accumulation, the wingspan of the specimen weight is the highest of all insulation materials under test. As seen in the EPDM case the wingspan is bigger in case the median differs from a long-term expected value.

There are fluctuations in the median between 1 ‰ in case of grease C to 5 ‰ in case of grease A. It is assumed that charge applied by handling and cleaning is a key reason for this weight fluctuation. Due to the viscosity cleaning should be the most intensive in case of grease C and the less intensive in case of grease A. This is in contrast to the fluctuation of the median of the specimen weight, increasing from the specimen with grease C to the ones with grease A. This means that the intensity of the cleaning procedure is no clear measure to the charge phenomena. Nevertheless in all the grease cases surface charge accumulation can be observed.

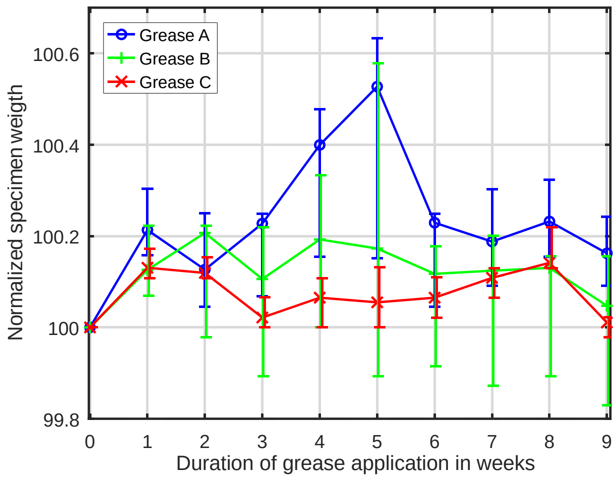


**Fig. 9** – Diffusion result of three different greases in XLPE without pressure

As the median of the specimen weights is nearly the same at the end then it was at the beginning it can be assumed that there is practically no diffusion of grease into the polymer, which can be explained by the different chemical structures of XLPE and both grease types.

## 4.4. Epoxy resin (EP)

The last material group investigated is an epoxy resin molding material, which is a mixture of epoxy resin and a filler. Thus, there are interfaces and irregularities in the insulation material allowing especially the oily components of the grease to penetrate it. In **Fig. 10** the course of the median and the wingspan of the specimen weight is displayed.

All specimen show the same final weight increase of 0.8 ‰ and an exponential saturation course of the median of the specimen weights. The wingspan of the specimen weight slightly increases during the grease contact time.

There are two possible explanations for the grease-independent weight increase: Either there is a grease-type independent diffusion or the preconditioning time of more than two weeks is not sufficient to achieve a steady state concerning the humidity. The first point is supported by the fact that both greases chemically differ strongly to EP and $Al_2O_3$ serving as filler and thus the oils can be trapped at the interface of the filler inde-pendently of its chemical structure.

In a second experiment, the preconditioning phase is elongated. The water content in the specimen is saturated after two weeks and so no significant weight increase is measured in the further weeks.

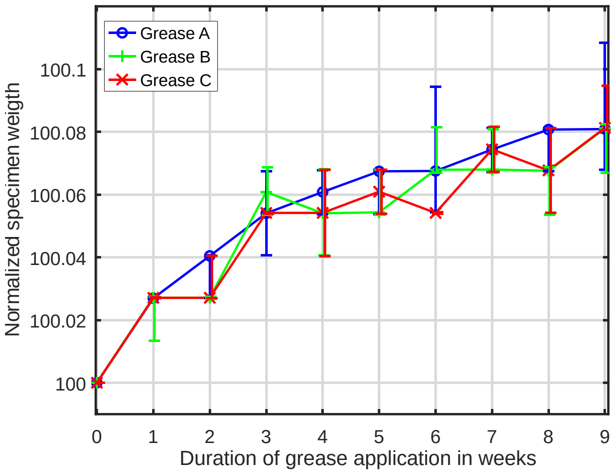


**Fig. 10** – Diffusion result of three different greases in EP without pressure

## 5. Conclusions

Diffusion of the grease respectively the oily phase of it in the organic insulation materials is one of the key parameters influencing both the mechanical and electrical long-term properties of MV and HV cable joints and terminations. Thus, proper selection and long-term testing of the suitable lubrication is vital. With the higher fluctuation due to the increase in share of renewable sources, the long-term thermal-mechanical requirements increase nowadays.

The long-term behavior depends on both the grease and the organic insulation material as well as on the interface pressure in case of a SiR-based grease on SiR insulation material.

For silicone rubber the highest diffusion can be seen by usage of silicone-based lubrications. Additionally, the diffusion of silicone-based grease is pressure-dependent. In contrast to this, there are PTFE-based greases available, which are showing no diffusion in SiR. In EPDM, EP and XLPE the diffusion is at least one order of magnitude lower. In EPDM, there might be a washing-out of ingredients as there is a weight decrease by applying grease A. In EP, the slight diffusion is independent of the type of grease applied. In XLPE, there is practically no diffusion measurable and the weight fluctuation is mainly driven by the accumulated surface charge.

## 6. References


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