Characterization of Transparent Fluorescent Silicones for Optical Monitoring of High-Voltage Cable Accessories

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ABSTRACT

The mechanical and electrical properties of new transparent silicone materials modified with two fluorescent dyes were investigated by measuring stress-strain behaviour, electrical breakdown strength, capacity and dissipation factor, before and after thermal ageing, as well as electrical and optical partial discharges.

Mechanical properties of the new materials are comparable to the reference and the addition of dyes stabilises them against thermal ageing. All materials are equivalent in terms of breakdown strength and capacity. The added value of transparency and fluorescence make them suitable materials for novel diagnostic applications in HV cable accessories and insulators.

KEYWORDS

Silicones, fluorescent dyes, partial discharge, electrical treeing, breakdown strength, tensile strength, elongation at break, thermal ageing

INTRODUCTION

Current monitoring systems for high-voltage (HV) cable accessories are realized on the basis of electrical measurements. The diagnostics of HV cables accessories relies on voltage test and insulation resistance measurements. In some cases, partial discharge (PD) measurement systems are used as well. Unfortunately, those systems are heavy, expensive, and complicated to use. Furthermore, the results often contain inaccuracies. In addition to that, electrical measurements are very susceptible to electromagnetic interference. Therefore, alternative methods are explored which do not suffer from these limitations and which will be more accurate, reliable, and insensitive to any interference.

One solution to this problem is the optical detection of partial discharges which demands the use of transparent insulation materials for cable accessories, such as optically clear silicones. Non-transparent silicones have been used in HV engineering for many years [1]. They show very good insulating properties and – being elastomers – they can be extremely flexible. Key benefits from silicones are their high electrical resistivity, resistance to environmental degradations and to electrical ageing as well as their hydrophobicity, which results in lower assembly and maintenance costs [2, 3].

Highly transparent silicones have not been widely used in high voltage applications so far. The aim of this work was to investigate these materials in terms of their mechanical and electrical properties and compare them to non-transparent silicones which are already used in HV applications. In addition to this, transparent silicones were modified with fluorescent dyes in order to enhance the optical PD detection sensitivity.

EXPERIMENTAL

Materials

PS 60 is a pourable, non-transparent, addition-curing, two-component silicone rubber that cures at room temperature. It was obtained from commercial sources and is typically used for cable accessories and insulators. PS 72 is a pourable, highly transparent, addition-curing, two-component silicone rubber that cures at room temperature. It is typically used for prototyping and potting of electronic components. PS 76 is a new highly-transparent addition-curing, two-component silicone rubber that cures at high temperature above 120 °C.

FD 1 (green) and FD 2 (orange) are two fluorescent dyes functionalised so that they can covalently bind to silicone PS 76. Both dyes were produced in our laboratories with very high purity ≥ 99% and they were used to modify the silicone rubber PS 76. For the modification each dye was chemically attached to a low molecular weight H-siloxane. The solvent was evaporated and the catalyst was removed from the reaction mixture and the reaction product was homogeneously distributed in the PS 76 matrix. After that the silicone was cured.

Sample Preparation

Mechanical and Electrical Test Samples

Special care was taken to produce bubble-free, plane-parallel sheets sized 100 × 100 × 2 mm from the silicones. Silicone components were mixed according to manufacturer’s recommendations and evacuated in a vacuum oven until the foaming mixture collapsed. The mixture was poured into a sandwich mould consisting of glass and polycarbonate plates and evacuated again until a defect-free surface was obtained. The mould was then closed with a second set of polycarbonate and glass plates. The sandwich arrangement was then clamped to prevent movement during curing. Curing was performed for 1 h at 100 °C for PS 60, 2 h at 120 °C for PS 76. After unmoulding, paddle-shaped specimen were die-cut from the silicone sheets, according to DIN EN ISO 527-2 type 5A for the mechanical tests. Optical markers were attached to the paddles in a distance of 20 mm. Electrical tests were performed on the 100 × 100 × 2 mm sheets.

Breakdown Voltage Samples

Samples for breakdown voltage measurements were produced in a similar way to the mechanical samples as thin films with a thickness of 0.5 mm. The films obtained were used for measurement without further processing.