Mechanical and chemical degradation assessment of polymeric cable components subjected to different accelerated ageing methods

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ABSTRACT

This paper investigates the ageing of polymeric components of a low-voltage cable extensively used at CERN. Looking for a time- and cost-effective accelerated ageing process, mechanical and chemical characterization techniques were used to study polymer degradation for different conditions (thermal ageing, gamma irradiation and their sequential combinations), at different doses and dose rates. Similar effects on the EaB are found for the two considered dose rates and when comparing irradiation only with the combined ageing conditions. Furthermore, OIT is observed to be early-damage sensitive and hypotheses on structural changes occurring at the different conditions are made based on Tm values.

KEYWORDS

Ageing; Cables; Polymer degradation; Gamma irradiation; Thermal ageing; Dose rate effect; Synergistic effect.

INTRODUCTION

Cables installed in some areas of the particle accelerator complex at CERN undergo severe degradation due to their specific service conditions, which involve different stressors like radiation and mechanical stresses. Polymeric components - which have insulating and protective functions within the cable - can degrade, generating operational failures and constituting a safety issue. For this reason, the mechanical and dielectric properties of polymeric components must be preserved during the whole service life of the cable.

The CERN Cable Ageing REsearch (CARE) project aims at monitoring the degradation of polymeric components of cables under radiation in order to identify cables which can have the longest lifetime under CERN service conditions. In this way, cable replacements due to radiation can be reduced to optimize resources: new cables, de-cabling and cabling works and the amount of time and manpower needed for work in high radiation areas, as well as to decrease the need for radioactive waste treatment (activated cables). Most of the cables in service at CERN are exposed to mixed-field radiation, with heterogeneous parameters of the field causing complications during the study of polymeric cable components degradation. Since the change of material properties is expected to only slightly depend on the type of radiation [1], ^{60}Co gamma radiation is often used because of easy access and replication, as well as the fact that it does not activate the material. For qualification purposes cable samples are subjected to accelerated ageing processes, including thermal ageing and/or gamma irradiation at high dose rates [2], in order to simulate real service conditions in a short time, after which their properties are evaluated relative to those of the corresponding unaged cable samples.

When applied in sequence, thermal ageing and irradiation are expected to have a synergistic effect [3]. Furthermore, it is expected that the most severe degradation would be induced when irradiation is followed by thermal ageing [4] because of chain reactions involving thermal-induced oxidation of radicals formed during irradiation, and a subsequent breakdown of the formed thermally labile oxidation products [5]. However, different behaviours can be observed in different materials, especially in industry-grade polymers, whose exact composition, including fillers and additives, is not fully disclosed.

An important factor influencing the result of irradiation performed in air is the dose rate. At high dose rates the oxygen is consumed mainly at the surface of the sample, as the rate of oxidation reactions is faster than oxygen diffusion into the material, leading to a heterogeneous degradation only restricted to a thin surface layer, which can lead to an overestimation of the lifetime for in-service cables. This phenomenon is known as Diffusion Limited Oxidation (DLO) [6]. In the context of accelerated ageing for qualification purposes, dose rates up to 10 kGy/h are used [2]. However, due to the dose rate effect, the degradation of the material might not be representative of the degradation of cables in service, which are subjected to at least an order of magnitude lower dose rates.

In this work cable samples were submitted to gamma irradiation and the effect of two different dose rates on polymeric cable component degradation was investigated to find a time-effective accelerated ageing process. Since gamma irradiation is cost-demanding, cable samples were also submitted to thermal ageing as well as to combinations of thermal ageing and irradiation, with the goal of finding a time- and cost-effective accelerated ageing process. In particular, five doses were chosen in accordance with the expected dose over the in-service lifetime of the considered cable.

Different techniques can be used to evaluate material properties. However, a clear correlation between the test results and the damage produced in the material is a major concern, which narrows down the number of tests and parameters suitable to assess the ageing state of the material. The Elongation at Break (EaB) determined by the Tensile Test (TT) is internationally recognised as a reliable parameter for assessing the damage of a wide range of materials used as insulation in electrical cables