Self-healing cable sheaths in extruded polymeric power cables

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ABSTRACT

Underground cables (UGCs) play an important role in power distribution networks. While UGCs have many benefits compared to overhead lines, manufacturing and installation costs are significantly higher. The prohibitive cost of accessing UGCs to carry out preventative maintenance means that many cables fail prematurely.

Here we describe two potential routes to develop cables that can autonomously repair or mitigate damage to the sheath. These are deployed as extrudable sub-sheath layers providing hydrophilic swelling response or intrinsic self-repair capacity. These systems are found to be capable of repair even under extreme conditions. These materials outperform existing water blocking tape technology and simplify cable production.

KEYWORDS

Self-healing, self-repairing, power cables, polymers, materials

INTRODUCTION

Underground cables (UGCs) form a vital element of power distribution networks worldwide. They are used in situations where overhead lines (OHLs) would be considered unsuitable, either because of the need to reduce visual impact or to meet the requirements of urban and city centre environments. These networks are extensive and growing quickly; within Europe, there are approximately 4.5 million kilometres of underground circuits with an anticipated growth of 4-5% per annum[1].

UGCs possess a number of advantages compared to OHLs, including resistance to extreme weather and reduction in visual impact. However, these are offset by the increased costs of materials and installation, which increases sharply with increasing voltage. Although LV UGCs may have an approximate cost ratio of 2:1 compared to their OHL counterparts, the cost ratio for HV UGCs may be as great as 20:1[2]. Furthermore, the location of these cables often prohibits preventative maintenance, which can allow an otherwise minor defect (which can be introduced at any point in manufacturing, installation, or operation) to progress, over years, to the point where it can threaten cable integrity. Should the cable subsequently fail, the difficulty in accessing the cable significantly prolongs the process of locating, diagnosing, and fixing the fault. It is estimated that fault resolution on UGCs takes up to 25 times longer than a comparative failure on an OHL[3], and risks significant disruption if the failure occurs in an urban area.

An elegant solution to these problems would be to develop cable materials that are capable of responding to damage events, or the driving forces associated with these events. These materials would aim to seal defects and prevent the free ingress of water, which is heavily implicated in accelerating cable deterioration including cable insulation failure via water treeing. It is thought that this would largely mitigate early cable failure by repairing small defects before they can develop further. In turn, this would represent substantial savings for distribution network operators by reducing the time and effort spent locating and resolving faults.

We propose two repair routes that would be suitable for this application; molecular self-repair, which could seal the defect and restore cable integrity, or a swelling response to water exposure, which could repair the breach and prevent further water penetration. Here, we present research-based suggestions and considerations for both approaches, with a focus on the deployment of these materials as a discrete, sub-sheath layer. We believe that the incorporation of this layer greatly simplifies the development of self-repairing cable designs that can be manufactured by conventional extrusion methods.

SELF-HEALING MATERIALS AND MECHANISMS

Self-healing materials can, by a variety of mechanisms, recover their material properties in the wake of a damage event. This ability confers a number of advantages to a material, including enhanced resilience and operational longevity, and so is of great value to structures which are either difficult or very expensive to replace. This process can be considered to be analogous to wound healing in nature.

Self-healing materials can be divided into ‘intrinsic’ and ‘extrinsic’ materials. Intrinsic materials possess the ability to repair the polymer matrix in the absence of any healing agents[4]. Typically, this relies upon the presence of labile bonds that can be broken and subsequently reformed in the wake of a damage event. Extrinsic materials usually rely upon healing agents held within microcapsules[5] or hollow fibres[6] that are released upon damage and react to form a solid plug in the damaged region. Examples of both are shown in Figure 1.

Both repair concepts possess strengths and weaknesses, which must be carefully considered when deciding on the most suitable repair method for each application. The main advantage of extrinsic repair materials is their reliability; as they do not require an external stimulus to operate, damage can be repaired almost irrespective of environmental factors. However, most extrinsic repair