Material development approach matching to an injection moulding rejuvenation for cable insulation failure

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Abstract. This paper aims to construct a material developing approach matching to an injection moulding rejuvenation technique for cable insulation failure. The work starts from a chemical composition testing to the cable original insulation material. The applied composition should be determined by considerations of property requirements, including insulation, mechanical behaviour and environmental adaptability. In addition, a stable and standard manufacture technology should be groped to assure having a stable repair quality. Finally, proper material should be verified by testing for meeting normal the cable insulation requirements. By the above approach, typical material development is performed and the results by a code-based insulation property testing reveal the present approach has successfully been applied to develop a proper material matching to injection moulding rejuvenation technique for cable insulation failure.

1. Introduction

The special failure of cable insulation mainly includes water tree defect failure, electrical tree defect failure and mechanical defect failure. Nannery et al. \cite{1} utilized dry N2 as the repair medium to repair the water tree defect of the cable. Through the comparative test, it was found that the insulation performance of the cable had been improved to a certain extent. Faremo et al. \cite{2-3} used hydrophobic compounds to repair the water tree defect of cables, in which the hydrophobic compounds such as ethanol and fatty alcohol was used as repair media. Bertini et al. \cite{4-5} researched and promoted the siloxane repair fluid technology commonly used in cable repair, which is adopted to repair water tree defect and electric tree defect.

Generally speaking, the repair technology for cable insulation failure can be divided into two categories. In view of the failure of water tree defect and electric tree defect, many scholars have developed a kind of comprehensive repair method of liquid injection chemistry, which injects the repair liquid into the defect position between the cable insulation layer and the conductor. The repair fluid reacts with water molecules to form a material with dielectric parameters similar to that of cable insulation material to fill the water tree channel, so as to remove the water in the channel, and make the electric field distribution of the original defect position tend to be uniform. The above repair methods are based on the conventional maintenance thinking of repairing without expanding product
damage. They generally have defects such as complex repair situation, high difficulty, limited and uncertain repair effect, and sometimes even affect the repair effect due to the side effects of maintenance.

Modern electrified rail transit is a huge cable network world, it has strict requirements for electrical conductivity, environmental safety, ageing resistance and mechanical strength[6]. At present, rejuvenation effect is objectively uncertain, and there is still a lack of relevant technology and quality verification technology to guarantee the correction quality. In view of the abnormal and accidental failure of cables, we have carried out a series of research work on the repair process of ethylene propylene insulated/chlorosulfonated polyethylene sheathed locomotive and rolling stock, and put forward the complete repair technology of local injection moulding for cable insulation failures. Rejuvenation matching materials of local injection moulding of cable insulation failures is then introduced below.

2. The proposed rejuvenation technique

2.1. Ideas of the rejuvenation technique

Breaking through the traditional thinking, we present the standardized geometric shape removal of insulation/sheath materials of cable insulation failure position. It is composed of three aspects, repair material matching the original insulating sheath, standardized injection mould and repair process, and standardized repair quality inspection accreditation rules.

Generally, whether a maintenance technology can be applied to production is not a question of whether it can be repaired or not, but whether the maintenance effect can meet the requirements of acceptable production. As mentioned above, the cable belongs to electrified rail transit or power production and transmission, urban power supply and other departments, whose maintenance effect is required by high quality. The cable insulation failure repair technology can be produced and applied only if the standardized process conditions and the maintenance effect are inspected according to the acceptable standardization, and it is proved that the acceptable maintenance technology can be met.

2.2. Technical elements and injection molding process

The core technical elements of the proposed rejuvenation technique on local failures of cable insulation include the following aspects: ① cable (1) to be repaired, ② inner and outer insulation/sheath material (2 or 3) to be repaired, ③ mould (4 or 5) for direct repair of inner and outer insulation/sheath, ④ mould (6 or 7) for indirect repair of inner and outer insulation/sheath, ⑤ injection moulding machine (8), ⑥ mould temperature machine (9), ⑦ repair mould (10 or 11) for inner and outer insulation/sheath, ⑧ repair adhesive for soft insulating material (12), ⑨ related process and quality assurance methods.

At present, there exist two possible repair routes for this technique according to the actual production situation, that is, direct and indirect injection rejuvenation. When the inner and outer insulation/sheath repair materials have good injection moulding process, direct injection moulding process can be applied to achieve cable repair.

3. Practice

3.1. Matching cable insulation/sheath repair materials

As a typical application of cable repair, it takes the insulation failure rejuvenation of rubber sheathed flexible cable of ethylene propylene diene terpolymer (EPDM) insulation/chlorosulfonated polyethylene as an example, production applicability of the rejuvenation technique of partial injection moulding for cable insulation failure developed by our team is verified.

Through the sampling and formula test of cable insulation/sheath material, the formula of rejuvenation material is determined, and the injection moulding granular material which matches the rejuvenation of cable inner and outer insulation/sheath is prepared, as shown as Figure 1.
a. Sampling for formula inspection.  b. Inner rejuvenation material. c. Outer rejuvenation material.
Figure 1. Self-machined injection plastic rejuvenation materials for inserting spaces of eliminated cable insulation and sheath layers around failure location matching to original ones.

3.2. Standardized injection mould and process.

3.2.1. Local active removal strategy for insulation/sheath of cable with insulation failure
It is necessary to ensure that the size of the inner layer is enough to handle the local insulation problems. According to the geometric mode of short inner layer and long outer layer, the outer layer is longer to cover the inner layer, so as to ensure that the sheath covers the inner layer, and form a dislocation reliable seal. In case of any local failure of the same type of cable, the same cutting strategy is adopted. Figure 2 shows the photos of partial removal of cables.

a. Cables with cross section of 120 mm². b. Cables with cross section of 70mm².
Figure 2. Samples of delimited sections with the standard local geometries around failed locations.

3.2.2. Standardized injection rejuvenation mould.
According to the principle of matching cable local cutting geometry, the basic work of mould technology includes two aspects. Firstly, a standardized direct repair mould with corresponding cable and repair space of 1c/1d is designed and constructed. Secondly, the injection mould with matching volume and width, slightly higher thickness and shorter length need to be design and build. In this way, the same type of cable insulation failure can be applied to the same model of mould repair.

Meantime, considering the delivery of repair materials, the mould design must have a feeding channel corresponding to the interface of the injection moulding machine. In addition, the mould needs to be designed with a channel connected with the mould temperature machine and through the circulating oil. Figure 3 shows the photos of practical moulds for direct injection rejuvenation mould and rejuvenation film preparation mould.

a. Injection moulds. b. Moulds for rejuvenation films.
Figure 3. Standard moulds for the present local injection rejuvenation technique.
3.2.3. Standardized repair process.
It is necessary to melt the repair material smoothly and send it into the cable space to be repaired for moulding, pressure maintaining and cooling, so as to make the repaired insulation and sheath have the best insulation conductivity, mechanical damage resistance, high and low temperature environment and non-toxic flame retardant performance. Only one of the best injection moulding processes can match each repair material. Therefore, it is necessary to find out the best injection moulding repair process of each material through experimental repair, and realize its standardization.

Figure 4 shows the injection moulding machine and mould temperature machine used, in which the feeding capacity of the injection moulding machine can reach 140g each time, the melting temperature can reach 200℃, the injection pressure can reach 1170 kg/cm², and the clamping capacity is 45t. Meanwhile, the working temperature can reach 220 ℃, and the oil circulation flow can reach 100 L/min.

By comparing the rejuvenation results of eight samples of cables with cross-sectional area of 120 mm² and 70 mm², the best rejuvenation process based on the preparation of insulation and sheath materials prepared by the research group is found. The photo of rejuvenation effect of two kinds of cross-section cable is shown in Figure 5.

3.3. Accreditation rules for standardized repair quality inspection.
Only through the repair process of cable performance verification, can it be applied to production. In order to solve this problem, attentions should be paid to the following production conditions.

- In general, extrusion process is used to realize the insulation/sheath manufacturing of cable, with large batch and no intermediate joint. The process of repairing and manufacturing is injection moulding, but the quantity is small, which is characterized by careful consideration of local joint. After the cable is repaired, the electrical conductivity test can not only measure the repaired part, but must be tested together with the insulation/sheath of the original cable. However, the existing inspection specifications have scale provisions, and the parts beyond the local repair scale can't be carried out according to the regulations. At the same time, the sample size of repair testing, even the special quality testing work, is quite limited.

- The manufacturing repair process can't be the same objectively, and the preparation of raw materials and repair materials can't be synchronized objectively. Even if the repair material is prepared according to the matching principle, it is very difficult for the repair material and the
raw material itself. Therefore, there must be differences between the repair materials and the raw materials.

- The quality guarantee period has the manufacturer's promise. From the point of view that the insulation failure of the original cable usually occurs after a period of use, it is not scientific to require the performance index of the repair material as that of the cable manufacturing quality. Therefore, the quality inspection guidelines for cable rejuvenation are defined as following aspects.
- The conductivity and insulation is the basic index of cable operation. The conductivity under extreme working/ reference inspection environment including resistance and breakdown voltage should be tested. It should be noted that the detection object is for the cable including the repair scope, and of course, the original insulation / sheath part can be covered.
- Flame retardant and non-toxic are the performance indicators of modern cables, which should be listed in the test column. Only when preparing the sample from the need of clamping the sample, its length is allowed to exceed the repair range. In the process of testing, it is necessary to control or distinguish between repair materials and raw materials.
- The mechanical properties under effective working environment/reference testing environment, including tensile strength, elongation and relative change rate of performance, are the basic performance requirements, so as to ensure the effective operation of cable insulation sheath, and should be included in the test.
- Considering the objective factors such as manufacturing repair means, environmental differences and the aging of the original cable insulation sheath material, the above test column and index requirements are allowed to be weaker than the new cable procurement performance, but should not be less than 85%, and the number of test samples should not be less than three.

Refer to the existing railway cable quality and performance test standard TB/T 1484.1–2010 [7], combined with the above guiding rules, the enterprise standard for performance testing of partial insulation failure rejuvenation of rubber sheathed flexible cable of EPDM insulation/chlorosulfonated polyethylene is proposed. Through the detection of two cable repair samples with cross-sectional area of 120 mm² and 70 mm², the effectiveness of the local injection moulding repair technology for cable insulation failure is also proved.

4. Conclusions
Following conclusions can be reached through the present work

- The rejuvenation technique of local injection cable insulation failure includes injection repair materials matching the original insulation/sheath material, standardized repair process, and standardized repair quality inspection.
- All kinds of failure of a cable can be completed by a standardized injection moulding process, which is a comprehensive and reliable production technology of cable insulation maintenance.
- The effectiveness of the whole set of technology is verified through the practice of partial insulation failure rejuvenation of rubber sheathed flexible cable of EPDM insulation/chlorosulfonated polyethylene.

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