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Fretting wear investigation of 1350-H19 aluminum wires tested against treated surfaces

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ABSTRACT

Fretting is known as the major failure mechanism in overhead power transmission lines. Wear is often observed in the conductor-suspension clamp interface, which is the focus of this investigation. Tests were carried out using 1350-H19 cylindrical wires fretted against flat discs with a load that mimics the real system. Two surface modifications are applied to the discs (a DLC coating and an anodization method) and compared with the state of the art system (SAE 305). The evaluated parameters are coefficient of friction, wear volume and wear morphology. A direct impact of the treatments on the wear volume and the wear mechanisms were found for each material pairing. Furthermore, distinct changes on coefficient of friction and material transfer were identified. Whereas the aluminum/anodized interfaces presented a low performance, the aluminum/DLC showed a significant improvement.

1. Introduction

The lifetime of overhead transmission lines is significantly affected by fretting wear [1,2]. This damage mechanism takes place at mechanical assemblies exposed to two combined loads: a normal load that pushes the two surfaces together and an oscillating tangential force, which can provoke a relative motion between corresponding material points at the contact interface [3]. In power transmission lines, these conditions occur at suspension clamps (where the conductors are fixed to the towers) or in the region where other metallic devices (e.g., spacers, dampers and aviation-warning spheres) are fixed to the conductor. Usually, the most critical point in terms of superficial damage to the power transmission line is the connection between the cable and the suspension clamp.

Within these assemblies occur a complex combination of loads. First, the conductor is loaded by a normal clamping force to guarantee a stable fixation [4]. Second, high static bending stresses arise due to the dead weight and the strong curvature of the conductors at the suspension clamp [5,6]. Third, the conductors are loaded with an additional tensile stress, which is applied to keep the safety distance between the conductor and the ground. Lastly, Aeolian vibrations [7] lead to cyclic movements of the conductor, which produces alternating bending stresses [8] and also relative movement amongst the wires and in the conductor/clamp assembly [9]. This combined action of fretting wear and fatigue stresses often generate fretting fatigue of transmission lines [10].

A conductor clamp system, depicted in Fig. 1a, consists of the following components: 1) a cable, 2) a semi-circular clamp that guides and supports the cable, 3) a rounded keeper used to press the cable against the clamp and 4) the U-shaped bolt used for restraining the system. The region (7) depicted in Fig. 1b represents the Crack Initiation Zone - CIZ, which is the area between the Keeper edge (5) and the Last Point of Contact - LPC (6). It is important to mention that the LPC is defined before the application of the variable loading and that under the keeper (8) no relative movements or only partial slip occurs [5,11].

In the CIZ, the forces that restrict the relative movement are related to the dead weight of the conductor and the restriction on the adjoined area (under the keeper). Due to these conditions, stick-slip or mixed slip is present [2,11,12]. This type of movement is the most severe one as it catalyzes fretting and wear damage [13]. Additionally to the clamping force, the relative movement between the two surfaces is hindered by the wedged asperities on the conductor and the clamp (microscopic effect). In case of increasing tangential forces the wedged asperity deforms and adhesive wear occurs. This leads to material transfer from the conductors to the clamp [14]. Cracks usually start from those pre-damaged wires in the CIZ.

As the movement restriction decreases with distance from the keeper's edge, gross slip takes place in the area after the LPC, which mainly generates fretting wear [12,13]. It is usually accepted that this type of wear damage is less critical for crack initiation due to a competition

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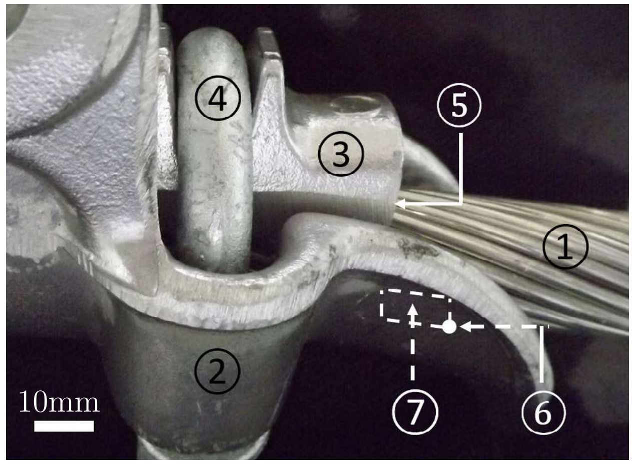
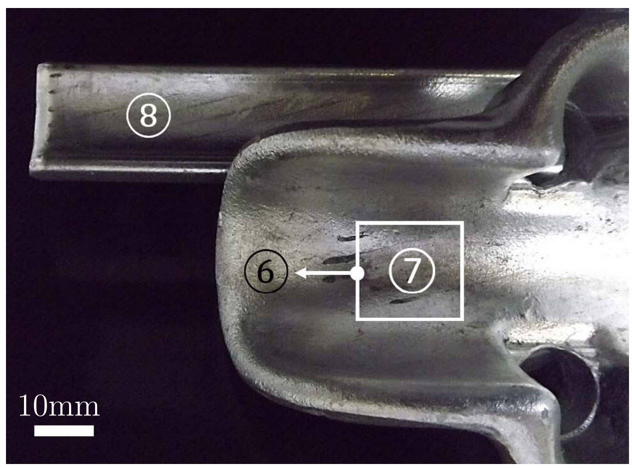


(a) Mounted system. 1) Cable; 2) Clamp; 3) Keeper (external surface); 4) U-bolt; 5) Keeper edge; 6) LPC (side view); 7) CIZ (representation).



(b) Detailed view. 6) LPC (top view); 7) CIZ; 8) Keeper (internal surface).

Fig. 1. Overhead conductor clamp system.

between wear and crack growth.

The analysis of this aluminum/aluminum contact configuration was carried out previously and can be found in [15]. As those results describe the state of the art system currently employed in power transmission lines, its main outcome is summarized here to allow a proper comparison of the results. The coefficient of friction (COF) of the Reference configuration showed a strong overshoot in the first seconds of the tests. These initially high COF values (approx. 2.0) could be related to the deformation of surface asperities. Subsequently, the COF decreased to 1.3. This decrease was explained by the formation of a tribolayer, which could be visualized with a microstructural analysis and identified by EDX measurements. Coherent with the COF curve progression, severe wire damage occurred in the beginning of the tests. After the formation of a tribologic layer, the damage was significantly decreased and stabilized. The wear analysis of both surfaces revealed that the main damage occurred on the wire. Further, it showed that the removed wire material either attached as an accumulative tribolayer on to the disc or was driven out of the contact zone and could be found as wear debris aside the wear tracks.

Overhead conductors consist of one external and multiple internal layers. Granted that wire breaks can occur in any layers, evidences for a preferred first wire break in the external layer were found in [5]. The reasoning behind this seems to be the presence of a mixed mode fretting fatigue regime in the CIZ. Therefore, an eminent potential for the lifetime extension of overhead transmission lines can be found by modifying the suspension clamp surface. Researchers found that a reduction in the COF led to a drastic reduction in the nucleation of cracks [5,16]. Therefore, clamps with modified surfaces could, in principle, promote a substantial improvement in this system.

To study this assumption, two surface treatments were selected: A Diamond Like Carbon coating (DLC) and an anodization method. The DLC coating was chosen due to its high hardness, its high wear resistance and its low COF [17]. The anodized surface was selected as a cheap method frequently used to protect aluminum surfaces. Moreover, it provides an increase in surface hardness and has a good wear resistance [18]. Different from the DLC coating, its COF is high. Therefore, an indirect conclusion regarding the impact of the COF on the damage of the conductor wires should be possible. In this contribution, we address the wear resistance of these two coatings in a fretting wear condition employing a cylinder-to-flat configuration using materials extract from the real components. We also discussed the implications of debris formation and material transfer. From the author's knowledge this has never been presented before and might lead to important findings for the aforementioned application. Considering that the costs of testing real overhead conductors are exorbitant, a tribological model test system was employed for the analysis of the coefficient of friction,