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Failure analysis of connecting bolts used for anchoring streetlights of a mountain highway

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ABSTRACT

This paper presents a failure analysis of connecting bolts used for holding streetlights inside the tunnels of a mountain highway. The fracture occurred in correspondence to crevices formed in bolted joints. Fractographic and metallurgical studies indicate that the bolt failure is due to a deep crevice corrosion process that is further aggravated by the presence of chlorides coming from the spray formed inside tunnels during the winter when sodium chloride is spread for de-icing roads.

Metallographic studies highlighted also that corrosion affects only bolts, while all the other joints' components are intact. EDS analyses revealed that the bolt material was a Cu-bearing stainless steel that, in chloride media, has a bad corrosion resistance because Cu destabilises the alloy passive film. Therefore, it is recommended that the bolt material should be changed to prevent similar failures and that in such environment crevices should be avoided in design.

1. Introduction

Streetlight fixtures are usually made of stainless steels that exhibit excellent corrosion resistance when exposed to the atmosphere due to their self-passivation properties. In fact austenitic stainless steels are widely used because they are alloys that are able to combine good mechanical properties and workability with considerable corrosion resistance. Despite that stainless steel components may be seriously damaged in service since in particular conditions they are susceptible to pitting, crevice corrosion and stress corrosion cracking that can cause catastrophic failure of metallic structures. The formation of deep localised corrosion defects is critical in components that are subjected to mechanical tensile stress because these defects are stress concentration sites that can lead to the initiation and propagation of cracks. The proneness to corrosion depends primarily on the specific aggressive environment and on the steel composition. In fact it is well known that for example very low concentrations of chloride ions are able to produce a localised dissolution of the passive oxide layer, so initiating the pitting corrosion. Generally speaking the pitting corrosion resistance of austenitic stainless steel can be increased by increasing their content of chromium, molybdenum and nitrogen. Another alloying element often added to these alloys to improve their performances is copper that has a relatively high solubility (about 4%) in austenite [1–6]. Its addition determines an increase in the stacking fault energy of austenite with consequent improvement of its deep drawing behaviour. Moreover copper presence in these alloys can provide not only the precipitation hardening in martensitic stainless steels, but also the precipitation of epsilon copper on the stainless steel surface [7–10]. This allows to obtain a special

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class of antibacterial materials that are extensively used for the production of kitchenware, medical appliances and plants for food processing. The addition of copper to stainless steels is also known to improve their resistance to general corrosion by means of mechanisms that have been deeply studied [11–17]. Several authors reported that copper seems to have a dual beneficial effect in protecting steel from corrosion in aggressive environments. In fact not only copper deposition on the alloy surface avoids the anodic dissolution of steel, but copper, which is characterised by a low hydrogen overvoltage, favours the stability of the passive layer in acidic environments [18]. Although the beneficial effect of this element on stainless steel protection in sulphuric media has been satisfactorily explained, its effects in chloride solutions is still debated. Considering that there is scientific evidence that in stainless steels pits initiate in correspondence of sulphide inclusions, some authors [19] suggested that copper addition is able to inhibit this process because it determines the formation of insoluble Cu_XS. Others highlighted that copper in chloride media makes complex ions such as $CuCl_2^-$ that affect the deposited copper stability. Moreover it has been stressed that the effect of copper on pitting corrosion was different for ferritic and austenitic stainless steels [15].

In this work we analysed causes and possible remedies of a corrosion phenomenon that leads to the failure of the anchoring systems of some lighting bodies. The streetlights subject to this phenomenon are positioned in tunnels of an Italian mountain highway.

2. Materials and methods

The failed components were made of austenitic stainless steel. Digital photographs were taken before cutting specimens for analysis. The specimens for microstructure observation were polished up to 1 μm alumina. A scanning electron microscope (SEM) with an energy dispersive X-ray spectroscopy (EDS) was used for analysing the different components, the fracture surfaces and micro-area chemical compositions.

Anodic polarisation curves of the AISI 316 stainless steel and of the bolt material in 0.2 M H_2SO_4 and 0.2 M H_2SO_4 + 0.5 M NaCl solutions at 30 °C were made using a potentiostat. Specimens were polarised in an anodic direction at a scan rate of 20 mV/s. These specimens were polished to #800 finish.

3. Results and discussions

In order to analyse causes and remedies of streetlight failure two light fixtures were analysed: one taken in the highway tunnel and showing clear signs of structural failure and one never placed in service for any reference analysis. The lighting bodies (Fig. 1) are constituted by a casing made of stainless steel on which are fixed the brackets necessary for the connection to the cable trunking. The mounting system is constituted by a bridge-shaped bracket that is welded to the casing, a bracket having an angled profile used for tilting the headlight body and fixed to the bridge-shaped bracket by means of bolts and nuts, a metallic band with hinges for the connection to the cable trunking. The heads of the bolts are filed down in order to limit their thickness.

The streetlight placed in service is equipped with angled brackets and presents the failure of the bolts connecting them to the metallic band used for the connection with the cable trunking. Three of the four screws showing clear signs of corrosion are still present on the brackets. The lighting body is entirely covered with a layer of dust that during disassembly of the various components appears infiltrated between the brackets. In the areas close to the welds corrosion products are also visible, while on the casing corrosion pits are sporadically visible.

For the analysis of the streetlight that has been in service the following components were identified and encoded:

- Angled brackets that connect the bridge-shaped bracket to the band with hinges (S1 and S2).
- Brackets welded to the casing (S3 and S4).
- Metallic band with hinges for the connection with the cable trunking (F1).

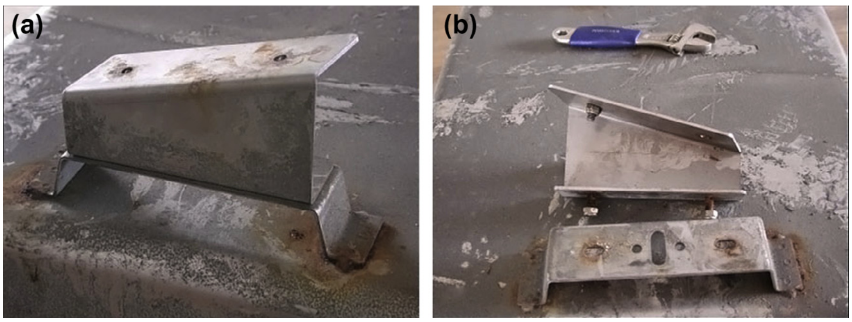

Fig. 1. Macrographs showing the bridge-shaped bracket fixed to the angled bracket (a) and the corroded bolts (b).