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Intergranular stress corrosion cracking of copper – A case study

B. Kuźnicka *, K. Junik

Institute of Materials Science and Applied Mechanics, Wrocław University of Technology, 50-370 Wrocław, Poland

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Abstract

The objective of this work was to identify the conditions and mechanisms for stress corrosion cracking (SCC) of a hard copper tube employed in a cooling system. The fractured tube was made of deoxidized high phosphorous copper (Cu-DHP). The identification was performed on the ground of fractography, metallography, residual stress measurements and corrosive environment analysis. It was found that humidity and environment containing ammonium and trace amounts of nitrite and nitrate ions were responsible for initiation of SCC yielding to breakdown of oxide surface layer by pitting. Cracking was found intergranular and perpendicular to circumferential stresses. Stress corrosion crack propagation appeared the most consistent with the oxide rupture mechanism. The findings were discussed in relation to the literature data in order to get a better understanding of cracking behaviour.

Keywords: A. Copper; B. SEM; C. Stress corrosion

1. Introduction

High-purity copper is immune to stress corrosion cracking in most environments and in the practical range of service stresses. However SCC of high-purity copper in specific corrosion environments has been documented [1–4]. Relating this fact to segregation of trace impurities at the grain boundaries is not convincing because of the two observed

* Corresponding author. Tel.: +48 71 320 2767; fax: +48 71 321 1235.
E-mail address: bogumila.kuznicka@pwr.wroc.pl (B. Kuźnicka).

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fracture modes: intergranular and transgranular. In addition, the effect on SCC-resistance of the dissolved element contents typical for commercial copper grades is not clearly determined.

In practice, SCC-initiated failure cases are noted of hot potable and heating water tubes [5–7]. The tubes are usually made of deoxidized high phosphorous copper (Cu-DHP) in annealed or cold worked temper. The common ammonia and nitrite ions are described to cause SCC, acting with residual stresses from the tube production, mechanical forming process and/or stresses resulting from internal pressure. Cracks, mainly intergranular, always start from the outer surface and propagate perpendicularly to the surface, predominantly in parallel to the tube axis.

In laboratory examinations however, mainly transgranular SCC of pure copper in nitrite or ammoniacal solutions and perpendicular to the tensile specimen axis have been found [1–3,8]. In a single work only [9] it was possible to initiate intergranular SCC of copper in nitrite solution.

The reason of this discrepancy is that both SCC initiation and crack propagation are determined by three factors: electrochemical, mechanical and physical, to the extent depending on their fraction. A change of fraction of any of these factors certainly affects the cracking mechanism. For this reason, a large number of models has been developed for intergranular and transcrystalline stress corrosion cracking, placing emphasis either on the electrochemical, electromechanical or the physical mechanism [8–13]. From among numerous models of intergranular SCC in copper, the most popular is continuous anodic dissolution process [1,8–10], but transcrystalline cracking is consistent with the discontinuous cleavage-like mechanism [2,10,13,14].

To get a better understanding of corrosion cracking behaviour in copper and to prevent such damage causes, it is necessary to collate laboratory results with SCC conditions during operation. This requires possibly precise determining the parameters of both electrochemical and mechanical processes that lead to service fracture of the copper components. The former ones include temperature, solution chemistry, electrochemical potential and the latter ones include state of stress (plane or uniaxial), level and type of stresses (tensile or compressive stress) and their distribution on cross-sections of the damaged components.

This work presents a detailed analysis of conditions of a copper tube service failure caused by SCC in relation with the referenced damage mechanism models.

2. Material and environment

The copper tube dia. 35 × wall 1.5 mm made a component of a cooling system with freon R404a under 1.7 MPa as the cooling medium. The damaged length of the tube was installed in an under-floor duct and directly covered with sand. The sand was covered with a layer of tar board and poured with concrete. After one-year operation, leakages appeared in form of longitudinal cracks (Fig. 1) concentrated within a strip at the tube top.

Stress corrosion failure analysis was performed on the grounds of corrosion products and corroding medium analysis, metallographic examination using optical microscopy and SEM, residual stress measurements and service load evaluation. Microscopic examination was carried out on longitudinal and perpendicular polished sections, unetched and etched with 10% water solution of ammonium persulphate.