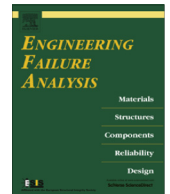




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Hot-water corrosion failure of a hard-drawn copper tube



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ABSTRACT

Deoxidized high phosphorus copper (C12200, DHP-Cu) is the principal construction element in piping in water distribution systems and HVAC (Heating Ventilation and Air-Conditioning) installations due to its excellent thermal and electrical conductivity, formability, corrosion resistance and antimicrobial activity. However, design and installation deficiencies or aggressive environmental parameters, such as improper water quality, may lead to unexpected failures causing material losses and many times property damage incurring high costs of repair. A corroded copper water tube caused leakage in a hot water hydraulic installation. The leakage was reported after approximately 6 years in service. Tubes were disconnected from a hydraulic installation and samples were taken for failure investigation. Failure analysis findings suggest strongly that the leakage was caused by tube perforation from the inner waterside due to localized pitting corrosion. The main cause of the accelerated tube pitting corrosion was the improper water chemistry (especially high chlorine content and low pH) inducing chemical attack of copper leading to scale layers of cuprite, chlorides and sulfates.

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1. Introduction and background information

Deoxidized-high-phosphorus (DHP) copper tubes are extensively used in water, healthcare, heating and refrigerant applications due to their high thermal conductivity, good heat transfer characteristics, excellent formability, corrosion resistance and antibacterial properties. Characteristic failures of copper tubes at various applications ranging from water supply to heat exchanger systems, may be attributed to pitting corrosion [1], intergranular cracking and corrosion [2,3], stress-corrosion cracking [4–7], fatigue [7], erosion–corrosion [8], and microbiological influenced corrosion (MIC) [9]. However, design and installation deficiencies or aggressive environmental conditions, such as improper water chemistry and stagnant water conditions, may be considered as very important contributors of pipeline unexpected damages.

A $\text{Ø}52 \times 1$ mm CuDHP hard drawn sample which exhibited leakage during service was received for corrosion failure investigation. The chemical composition of the DHP tube is within the range: Cu minimum = 99.90 wt.%, P = 0.015–0.040 wt.%, according to the EN 1057 standard and in compliance with other relevant specifications for water supply applications. The damaged area was properly marked. According to case history information, the installation has been completed since early 2006 and it was a part of a hot water circuit. Service time of the water installation is estimated to be approximately up to 6 years. According to background information, flowing medium is normal tap water which has been subjected to water treatment, i.e. chlorination. Usual circuit temperature was up to 50–60 °C while typical operation pressure ranged within 2–3 bar. Unfortunately, no other specific information on representative water chemistry used through service

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period could be retrieved. Optical and scanning electron microscopy coupled with Energy Dispersive X-ray Spectroscopy for local elemental analysis were employed for microstructural and morphological examination and were the main analytical techniques for the present investigation. Moreover X-ray Diffraction Analysis of the corrosion products was also performed to identify the main crystalline phases participated on the inner tube scale deposits.

2. Experimental procedure

Macroscopic observations were performed with a Nikon SMZ 1500 stereo-microscope. Cross-section of $\varnothing 52 \times 1$ tube was prepared using hot-mounting, wet grinding up to 1200 grit SiC paper and polishing with diamond and silica suspensions. Metallographic examination was conducted using a Nikon Epiphot 300 inverted metallographic microscope. Microhardness testing was performed in an Instron-Wolpert 2100 device using 200 gf applied load. Higher magnification microscopic observations were carried out on as polished sections using an FEI XL40 SFEG scanning electron microscope (SEM) equipped with an EDAX Energy Dispersive X-ray Spectrometry (EDS) detector for elemental analysis of selected areas. X-ray Diffraction of corrosion products was performed using Cu K α monochromatic radiation employing a Philips X'Pert Pro diffractometer with an X-ray Tube PW3373/00 Cu LFF DK117025 according to Refs. [10,11]. X Pert Organiser, Data Collector, Graphics & Identify was used as analysis software, while the determination and identification of crystalline phases was conducted through Crystallographica Search Match software based on standard spectra library (Powder Diffraction Files) PDF2.

3. Investigation findings

3.1. Visual examination and stereomicroscopy

Macrographs showing outer and inner tube surfaces are presented in Fig. 1, suggesting that corrosion processes initiated from inner tube surface. Stereomicroscopic observations indicated accumulation of corrosion deposits (green scale) adjacent to the leakage waterside region (Fig. 2).

3.2. Optical microscopy and SEM/EDS evaluation

Optical microscopy and SEM evaluation showed the complex layered structure of the corrosion pit close to the leakage (Figs. 3–7), indicating that the pitting corrosion initiated from waterside area and progressed towards outside surface leading to wall disruption and finally leakage. EDS microanalysis identified the exaggerated presence of chlorine attributed to the presence of chloride salts; sulfur, phosphorus and silicon were also detected mainly as upper layers on pit membrane (Figs. 5, 6 and 8). Chloride salts area principally found on the floor of the pit above the cuprite (Cu_2O) layer. Pit membrane is a

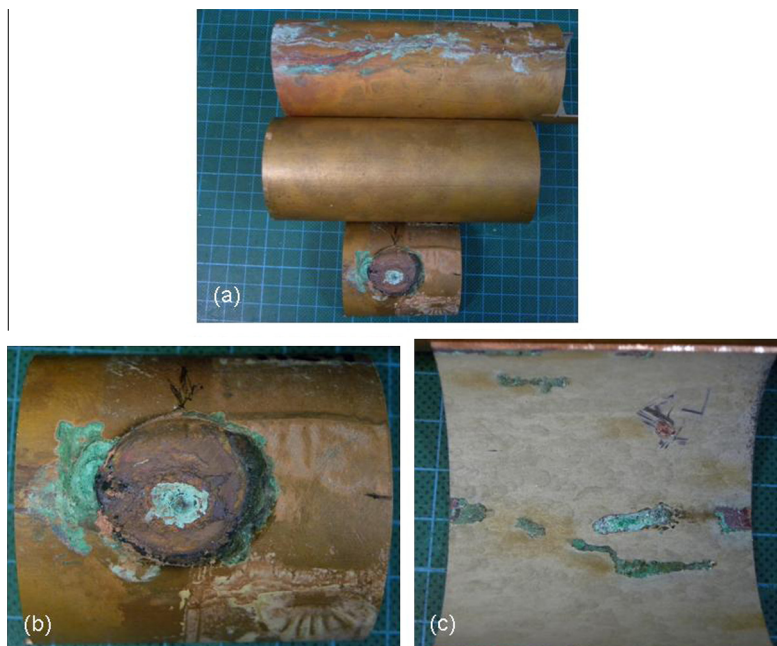


Fig. 1. Macrographs showing (a) the as received samples, (b) outer surface of the tube at the leakage area and (c) inner surface of the tube. The presence of corrosion products in the inner tube area is noticeable.

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