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Interactive effect of ant nest corrosion and stress corrosion on the failure of copper tubes

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ABSTRACT

Premature failure of copper tubes used in air-conditioning units is a serious problem for air conditioning manufacturers and customers. Several failure theories were put forward, such as ant nest corrosion and inter-granular stress corrosion. A new opinion is raised in this article that the interaction of ant nest corrosion and stress corrosion cause the failure of copper tubes. This article analyzes the interactive effect through comparing the morphologies of the failure copper tubes in practical application with the samples which were exposed to the concentration of 1 vol% formic acid vapor in airtight glass vessels for different days. The experiment results show that most of copper failures result from the interactive corrosion due to the morphology of interactive corrosion tunnels is thinner than single ant nest corrosion and the corrosion starting points of interactive corrosion tend to distribute at the bottom of internal groove where the tensile stress was concentrated.

1. Introduction

Copper is widely used in heat-transfer units such as evaporators, air-conditioners and refrigerators [1–3] due to the unique combination of relative strength, corrosion resistance and higher thermal conductivity. However, in the last century, large amounts of events about failure of copper tubes which used in air-condition have been reported. The mechanism of the failure had not been explicit until the formicary corrosion was first reported in the 1970s by Edwards et al. [4,5]. Then, varieties of theories and solutions about the copper corrosion were put forward successively. As for current situation, despite a lot of premature failure had been prevented effectively, a large amount of failures still exist. Formicary corrosion is also called ant nest corrosion. The term comes from the similarity of the morphology to an ant's nest [6]. A lot of literatures reported ant nest corrosion is a main type of premature failure of copper tubes used in air-conditioning units for polyol ester oil for carrying lubrication and cooling of compressor bearings [7].

Actually, since the reason that causes the failure of copper tubes is complex, single ant nest corrosion couldn't be used to explain these failures exactly. In our experiment, several morphologies of copper tubes' failures were observed and analyzed. Large quantities of cracks were observed on the surface and a few chlorine elements were detected. According to literatures [8–11], the cracks together with the existence of a chloride and organics containing medium, may lead to stress corrosion cracking (SCC). In other words, another possibility can be raised that the interaction of ant nest corrosion and stress corrosion caused the failure of copper tubes.

This article aims to study the interaction of ant nest corrosion and stress corrosion by means of comparing the morphology of the failure copper tubes in practical application with the original undamaged copper tubes in formic simulation experiment. The

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undamaged copper tubes are set in an airtight glass vessel where formic acid vapor are generated in our simulation experiment to obtain ant nest corrosion samples. Moreover, there don't have any corrosion medium which could induce stress corrosion in our simulation experiment thereby ensuring stress corrosion can't occur. The morphologies of tubes are achieved by grinding the tubes layer by layer and observing by metallographic microscope and SEM. The composition of corrosion products was analyzed by XRD and EDS.

2. Experiment

Several leakage copper tubes serviced in air-conditioning units were grinded layer by layer and taken photos by optical microscope directly. Several intact copper tubes were also used in our simulation experiment for ant nest corrosion. The tubes were set in an airtight 1 L glass vessel where formic acid vapor was generated to assure that only ant nest corrosion exists.

Copper tube specimens of 40 mm in length, suspended at 45° in glass test tube, were exposed to the concentration of 1 vol% formic acid vapor in airtight glass vessels for different days. At the same time, thermal cycling experiments were conducted, holding the temperature by immersing the airtight glass vessels in a thermostatically controlled water bath at 40 °C for 16 h followed by 8 h at 25 °C to cover the first 24 h cycle. Thermal cycling was continued for up to 30 days. Specimens were removed and analyzed after 15, 20, 25 and 30 days. An extra sample of pure copper powder was also prepared by the same process. These tubes containing the leakage points were sawn from the copper tube for microscopic test. The samples which ant nest corrosion had occurred were grinded layer by layer and taken photos by optical microscope continuously. Then the areas of leakage points were investigated by scanning electron microscope (SEM), EDS and XRD to analyze the composition of corrosion products.

3. Results

3.1. Morphology of the tube surfaces

Fig. 1 shows the surface morphology of leakage copper tubes which serviced in air-conditioning units. Fig. 1(a) & (b) are the morphology of outer surface and Fig. 1(c) & (d) are the morphology of inner surface. In Fig. 1(a) & (b), several micro-cracks can be seen obliviously. Actually, these micro-cracks are the laminations/folds which could have been produced during tube manufacturing. Besides, several pitting corrosion can be observed obviously on the inner surfaces at the areas with red marks and the partial magnify image of pitting hole is also shown in the inset in Fig. 1(c). In addition, the pitting holes are distributed regularly, almost all pitting distribute on the bottom of internal groove. In other word, the bottom of internal groove can be identified as the starting points of corrosion. As the Fig. 1(d) show, many micro-cracks are concentrated at the bottom of internal groove on the inner surface. These micro-cracks formed possibly at the initial preparation or using process of the copper tube due to the stress concentration [12] and

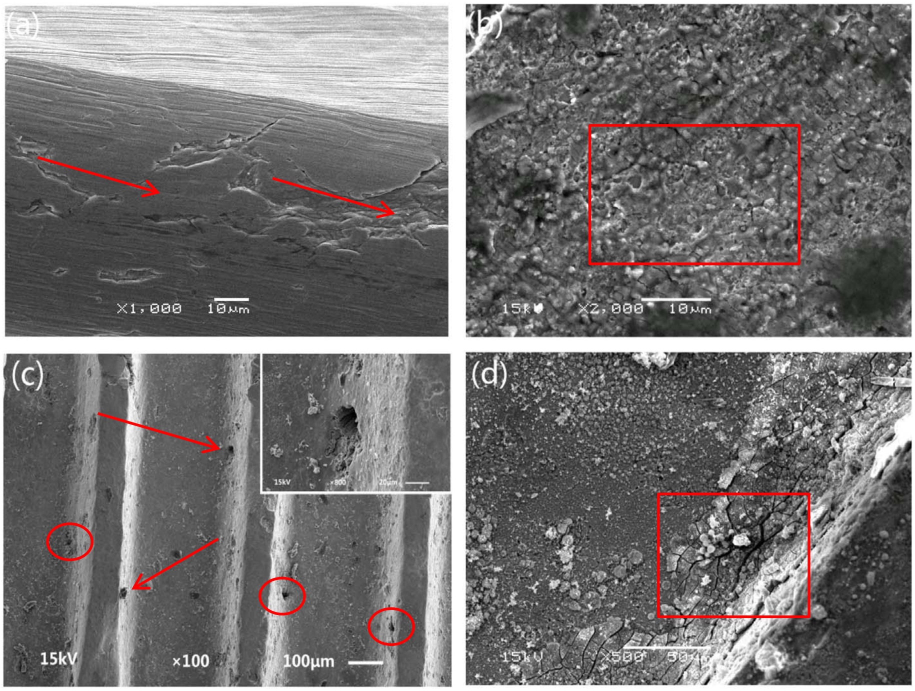

Fig. 1. The surface morphology of leakage copper tubes observed by SEM (a, b are the micro morphology of outer surface, c, d are the micro morphology of inner surface observed by SEM).