

Heat exchangers corrosion protection by using organic coatings

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Received 15 June 2007; received in revised form 24 October 2007; accepted 21 January 2008

Abstract

Corrosion phenomena in aluminium heat exchangers represent a problem in terms of durability and efficiency of thermal exchange. This work evaluates the barrier properties of two coatings that represent the state of the art for the protection in the heat, ventilating, air conditioning/refrigerating field (HVAC/R): electrophoretic coating (E-coating) using epoxy resin and spraying of polyurethane coating with addition of metallic pigments. The ability of the coatings to cover the surface of heat exchanger has been evaluated by means of optical microscopy in order to highlight critical zones of the system for the application of the coatings. The electrochemical behaviour of coated heat exchangers has been studied by means of electrochemical impedance spectroscopy in 3.5% NaCl solution. The local electrochemical behaviour of coating defects has been investigated using the electrochemical micro-cell, which enables to perform potentiodynamic polarization measurements on single defects. E-coatings evidenced difficulties to provide uniform thickness of the coating at the extremities of the fins. Spraying of the polyurethane coating containing pigments require particular care in order to fully cover zones of the heat exchanger with difficult accessibility. The electrochemical behaviour of coated heat exchangers is affected by the existence of defects in the coatings.

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Keywords: Heat exchanger; Corrosion; E-coating; Metallic pigment

1. Introduction

Corrosion protection of heat exchangers is very important since these systems might work in environments containing different types of aggressive species. In particular, localized corrosion of the aluminium fins might compromise durability and efficiency of heat exchangers [1–3]. The state of the art for the protection of heat exchangers for the application in the heating, ventilating, air conditioning and refrigerating field (HVAC/R) is represented by electrophoretic coatings (E-coatings) [4,5]. However, the deposition of coatings by electrophoresis is rather expensive. Therefore, the introduction of alternatives to electrophoresis is rather important for the HVAC/R field. An interesting possibility is the introduction of coatings containing metallic pigments in order to improve thermal exchange efficiency [6,7]. This enables the application of relatively thick coatings on heat exchangers possibly improving corrosion resistance. This is a very important aspect relative to application in the HVAC/R field because coating thickness should be selected

taking into account thermal exchange and barrier properties. The latter properties can be evaluated with electrochemical impedance spectroscopy, which is a well-established technique for the study of organic coatings [8–10]. In particular, this technique can be used to evaluate the effect of defects on the electrochemical behaviour of cathodic coatings [5].

The electrochemical micro-cell is a local electrochemical technique that was employed for the investigation of the corrosion behaviour of different materials [11–13]. This technique was not yet employed for the study of organic coatings. The main reason is that it is rather difficult to carry out impedance measurements with this technique [14]. Nevertheless, the application of this technique for the study of coating defects is considered very interesting by the authors due to the possibility to perform potentiodynamic polarization measurements on small areas (in the micrometer range).

This work investigates the morphology of heat exchangers covered with an E-coating and with a polyurethane coating containing metallic pigments (applied by spraying). In addition, it studies the barrier properties of the coatings on aluminium fins extracted from heat exchangers by means of electrochemical impedance measurements at room temperature and at 50 °C. Furthermore, the electrochemical micro-cell technique

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was employed to carry out potentiodynamic polarization measurements at the locations of typical defects of the coatings.

2. Experimental procedures

The heat exchangers investigated in this work were produced with aluminium fins and copper tubes. The fin material was an aluminium alloy of the 8xxx series with composition in the range indicated in Table 1. The thickness of the fins in the heat exchanger was 0.15 mm. Aluminium sheets made with the same composition as the heat exchanger fins were also supplied with thickness of 0.2 mm.

Heat exchangers were E-coated using an epoxy resin according to the standard procedure employed by the supplier for application in the HVAC/R field. The glass transition temperature of the epoxy resin is in the range of 100 °C. In addition, heat exchangers were painted with an innovative polyurethane coating incorporating aluminium pigments in order to improve heat exchange efficiency. Before application of the polyurethane coating containing pigments, a chromate-free conversion coating was applied on heat exchangers. The polyurethane coating containing pigments was applied by spraying. Its glass transition temperature is about 160 °C.

In addition to aluminium fins, aluminium sheets were painted by E-coating and with polyurethane coating containing metallic pigments. These coated sheets were produced as reference samples because these substrates represent an ideal substrate for coating deposition limiting possible defects due to the complex geometry of heat exchangers.

The ability of the coatings to cover the surface of heat exchanger was evaluated by means of optical, stereo and scanning electron microscopy (SEM) in order to highlight critical zones of the system for the application of the coatings. The electrochemical behaviour was studied by means of electrochemical impedance spectroscopy in order to evaluate the barrier properties of the coatings. Impedance measurements were carried out with an AUTOLAB PGSTAT12 potentiostat equipped with frequency response analyzer in 3.5% NaCl solution for immersion times up to 144 h. These measurements have been performed both on coated aluminium sheets and on coated heat exchangers. The amplitude of the signal was 0.01 V and the frequency range was 10^6 to 10^{-2} Hz. The area of the working electrode was 14.9 cm² for measurements on aluminium sheets. Due to the rather small fin collar spacing (21 mm) in the delivered heat exchangers, a special electrochemical cell was developed

in order to perform impedance measurements on the fin surface. This cell was positioned on the fin using an O-ring, which defined the area of the working electrode (1 cm²). An Ag/AgCl reference electrode and a platinum counter electrode were employed for all measurements. Electrochemical impedance spectroscopy measurements were carried out on samples immersed in solution at 50 °C. This temperature was indicated by the heat exchanger supplier in order to evaluate the electrochemical behaviour of the investigated systems under conditions similar to the working ones. In order to perform measurements at 50 °C, the electrochemical cell (consisting of a PVC tube glued on the sample surface and containing the electrolyte) was heated in an oven. The electrochemical micro-cell [11] was employed for investigation of the behaviour of typical defects found on aluminium painted with the coatings investigated in this work. Glass capillaries with internal diameter of 200 µm were used to perform potentiodynamic polarization measurements at defect locations. The reference electrode was Ag/AgCl and the counter electrode was a Pt wire.

3. Results and discussion

Fig. 1 shows an optical micrograph of the cross-section of an aluminium fin painted with epoxy resin (E-coating). This is a section of the flat part of a fin in the region between two adjacent collars. The E-coating uniformly covers the fin and exhibits a thickness in the range of 20 µm. The edges of the fin (not shown here) might present reduced thickness due to the low wettability of these sharp edges.

The micrograph in Fig. 2 shows defects that might be present on E-coated aluminium fins. The defects appear as coating discontinuities (possibly pin-holes), which might expose the bare aluminium to the attack of aggressive species. It is also possible that these defects are coating agglomerations that might impair the barrier properties. Similar defects were observed on copper fins painted with the same type of coating. In this case, the defects are mainly pin-holes since the copper substrate is often visible.

Fig. 3 exhibits a SEM micrograph of an aluminium sheet painted with polyurethane coating containing aluminium pigments. The pigments appear brighter than the organic matrix

Table 1
Composition (wt%) of the aluminium alloy employed for production of heat exchanger fins

Al	Balance
Si	Maximum 0.40
Fe	1.2–2.0
Mn	0.1–0.3
Mg	0.1
Cu	0.3
Zn	0.1
Other	Maximum 0.05

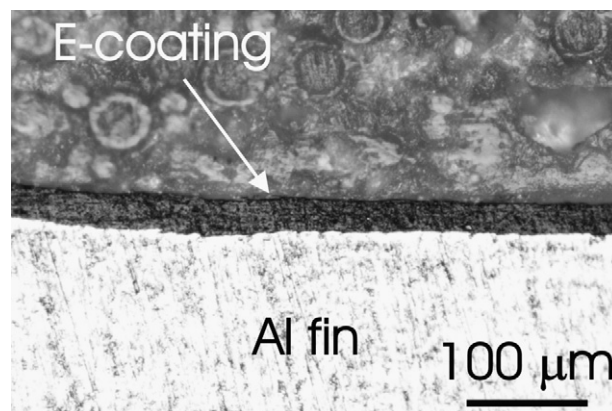


Fig. 1. Optical micrograph of the cross-section of an E-coated aluminium fin.

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