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Self-healing performance of an epoxy coating containing microencapsulated alkyd resin based on coconut oil

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ABSTRACT

The microcapsules (MCs) containing alkyd resin based on coconut oil with different concentrations: 5, 10, and 15% were incorporated into a commercial epoxy coating and the coating was then applied on steel panel substrate. The effect of incorporation MCs on properties of the coatings was evaluated via assessment of surface roughness, gloss, adhesion strength, and bending elongation of the coatings containing MCs and comparing them with the properties of control coating. Furthermore, the healing performance in the epoxy coating and consequently their ability to protect the substrate against corrosion of the scratched coatings without and with MCs were also investigated in 5 wt% NaCl solution using potentiodynamic polarization tests and Electrochemical Impedance Spectroscopy (EIS). The obtained results revealed that increasing concentration of MCs in epoxy resin caused to a decrease in gloss and adhesion strength as well as a reduction in bending elongation of coatings. A good agreement between potentiodynamic polarization and EIS results indicated when the MCs concentration was equal to 10%, the amount of the released healing agent (alkyd resin based on coconut oil) was adequate to satisfactorily heal the cracks.

1. Introduction

Metals and metal alloys have been widely used in structural buildings and construction throughout the world due to their high strength. However, a major problem of these types of materials is their tendency to corrosion. One of the most common and economical methods to protect materials against corrosion is using an organic coating [1–3]. Coatings increase the lifetime of a structure in corrosive environments by inducing a barrier between the metals and their surrounding environment. However, once a conventional coating is damaged due to external effects or a sudden impact, the protection will be lost. The self-healing ability, as a novel solution, was proposed as a way of developing the aforementioned materials to be smarter and provides enhancement in the lifetime of metallic structures. For this approach, micro/nanocapsules (containing healing agents) were incorporated within barrier coatings which can release healing agents after any occurred damages [4–7].

In the past few years, different self-healing strategies such as releasing healing agents, reversible cross-links, migration of nanoparticles have been developed, on how the first method is proving to be the most well-studied [8–12]. White et al. innovator the of this strategic for the first time, illustrated an applicable procedure to encapsulate dicyclopentadiene (DCPD) as a healing agent in a poly (urea-formaldehyde) (PUF) shell of MCs [13]. Presence of its catalyst in the coating matrix was a necessary part of the above-mentioned system, but catalyst as a second phase leads to a major heterogeneity in the coating matrix [14]. Subsequently, using an oxidative healing agent was investigated to solve this drawback. Samadzadeh et al. demonstrated the self-healing ability of encapsulated tung oil in PUF shell in the absence of any catalyst [15]. However, Thanawala et al. studied on self-healing coatings based on Linseed oil. In their study, the drying of the resin in the healing process was accelerated by using cobalt naphthenate and zirconium octoate. Moreover, the self-healing performance of encapsulated Linseed oil (as drying oil) was investigated via the corrosion resistance evaluations [16]. In another research, Linseed oil along with drier was selected as the healing agent. It was reported that released healing agent was able to heal the cracks [17]. Due to the presence of unsaturated fatty acids in Linseed oil and tung oil, these oil's molecules tend to crosslink with oxygen to make a stable complex and finally healed the damaged surfaces [16]. However, the drying process could be accelerated by using driers, based on cobalt, calcium, lead, and zirconium catalysts. Coconut oil as a non-drying oil has only 6.5 wt%

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unsaturated fatty acids [2]. For centuries, this oil has been used in paints and coatings. Alkyd resins, which are the result of the reaction of polyhydric alcohols and polyacids modified with triglyceride oils, can be designed to have a specific amount of carboxyl and hydroxyl groups as crosslinking sites [18]. It should be mentioned, due to the presence of the aforementioned functional groups, the alkyd and epoxy resins are compatible. Therefore to modify properties of a particular resin, usually for coating applications, alkyd and epoxy resins are blended (physically or chemically) [19–23].

In our previous work, as the first part of this study, a coconut oil-based alkyd resin (CAR) as the healing agent was successfully encapsulated into poly (melamine-urea-formaldehyde) (PMUF) as shell material via in situ polymerization process [2]. Subsequently, in the second part of the study, the aim is to employ the MCs in an epoxy coating in order to develop a self-healing epoxy based coating. The focus of this paper will be on evaluation of the MCs self-healing performance during the reaction of epoxy and CAR. It is expected that, when the damage occurs in the epoxy- based coating with embedded MCs containing CAR, MCs will break and the healing agent released simultaneously. Subsequently, CAR flows in the created cracks by capillary action, where carboxyl and hydroxyl functional groups inside CAR structure, as well as amine groups belong to MCs shell, chemically react with the epoxy resin. This reaction initiates, and the coating heals itself spontaneously. The related reactions are schematically illustrated in Fig. 1. According to Fig. 1, it is important to point out that the functional groups shown in the CAR formulation obviate the need for having C=C unsaturated bonds for reaction with oxygen. Moreover, in this research, the effect of incorporation MCs on some properties of the coatings including gloss, adhesion strength, and bending elongation tests was also characterized to examine the commercial feasibility of the coating. Afterward, potentiodynamic polarization, as well as EIS tests, were also employed to investigate the healing performance of the coating and consequently their ability to protect the substrate against corrosion.

2. Experimental

2.1. Materials

MCs containing CAR were prepared from materials and procedures specified in our previous work [2]. EPON 828 as a commercial epoxy resin, viscosity 11–15 Pa s [24], was purchased from Hexion and mixed with Diglycidyl ether of 1.6-hexanediol (ED 180) as the reactive diluent, viscosity 0.015–0.025 Pa s, which was provided from Inchem Ltd. Furthermore, a polyaminoamide (Merginamide A280), viscosity 1–2 Pa s and amine value 0.25–0.29 g KOH/g, was supplied by Hobum Oleochemicals and used as the curing agent of the epoxy resin. Sodium chloride (NaCl) was procured from Merck Co. Deionized water was used for all washing process and preparation of the solutions.

2.2. Preparation of steel panels and self-healing coatings

All the samples were coated on the same type of substrates. Initially, several pieces of ST 37 steel panels (150 × 100 × 1 mm^3) were polished with a soft sand paper to remove possible loose rust scale, and then the surface was degreased with a clean cotton cloth soaked in acetone until the clean cloth showed no discoloration. Finally, the steel panels were washed with deionized water and dried in an oven for 1 h at 100 °C.

The epoxy resin was mixed with reactive diluent (ED180) in epoxy/diluent 3:1 ratio to prepare a solvent based coating. The freshly prepared MCs were dispersed by mechanical mixer at 200 rpm for 5 min in the prepared epoxy resin at three different capsule content of 5 wt% (sample B), 10 wt% (sample C) and 15 wt% (sample D). All resins containing MCs and control sample (clear coat without any capsule which named as sample A) were mixed with modified polyaminoamide

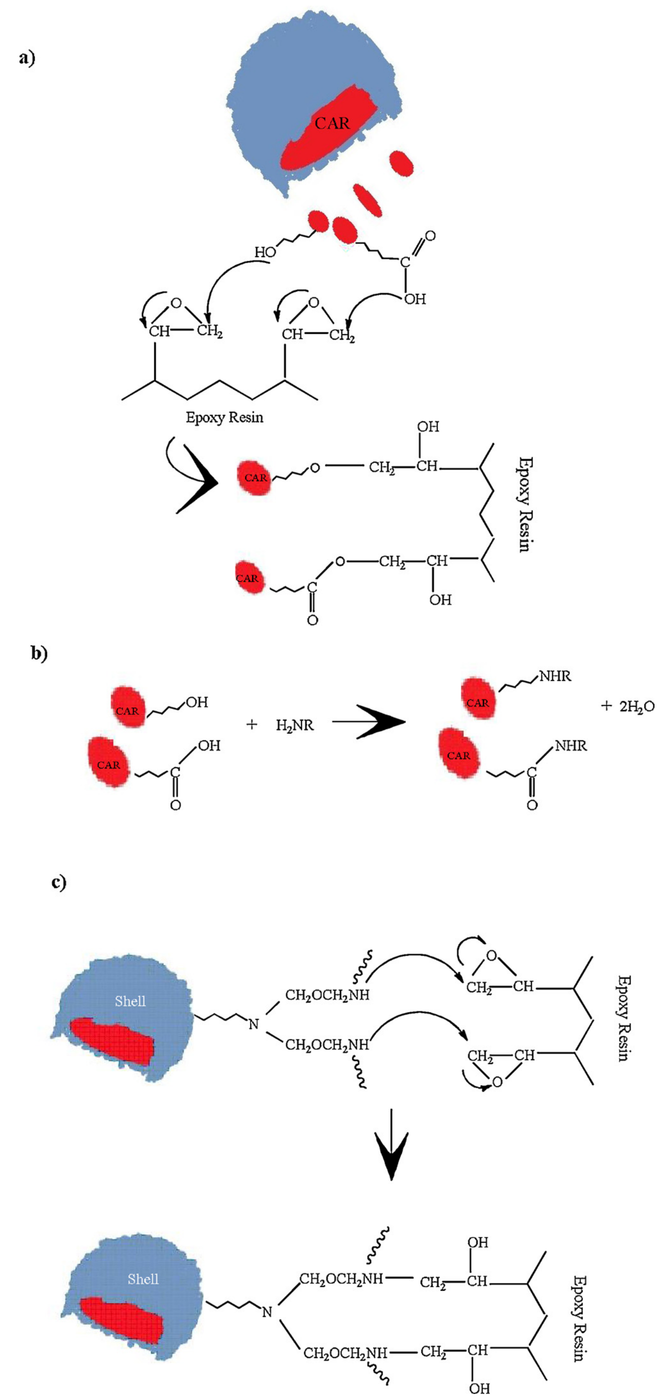

Fig. 1. Plausible reactions of functional groups in CAR structure with a) epoxy rings in an epoxy matrix, b) amine groups in curing agents and c) reactions of functional groups in shell of MCs with epoxy matrix.

curing agent with 100:58 mass ratio of epoxy and its curing agent before application. The aforementioned mixtures were then applied to the surfaces of the cleaned steel panels with a universal film applicator (ZEHTNER ZAU 2000.80) to create a uniform film coatings on the surface of steel panels. The prepared coatings were then cured at room temperature (25 ± 2 °C) for 7 days before undergoing the tests. The coatings of 300 μm wet thickness were applied using a Dry Film Thickness Gauge, Elcometer 456, Elcometer Instruments Ltd., Manchester, UK. The cured coatings were manually scratched (cross-cutting) by an Elcometer 1538 DIN Scratching Tool with 0.5 mm Cutter for EIS tests as described in our previous work [25]. The scratched