

Experimental study to evaluate the effect of polymeric encapsulants on the corrosion resistance of intermediate-level radioactive waste packages

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ABSTRACT

Intermediate-level radioactive waste is normally encapsulated in cementitious grout. However, for some wastes, grout may not be suitable and polymeric encapsulants are being considered as an alternative. One concern with such encapsulants is their long-term chemical stability and the possibility that release of aggressive degradation products could cause corrosion.

This paper evaluates the potential for three polymeric encapsulants: two epoxy resins (the APS polymer system, (APS) and Alchemix 4760 (ALC)) and a vinyl-ester styrene (VES); to cause internal corrosion of stainless steel waste containers. The corrosion behaviour of stainless steel 316L in contact with each encapsulant was studied in saturated Ca(OH)₂ solutions and deionized (DI) water, at 80°C, under non-irradiated and γ -irradiated conditions.

In aerated, alkaline conditions, 316L was resistant to corrosion in all the conditions tested. However, in DI water, the pH fell to values as low as three due to release of acidic species from the polymers. The two epoxy materials (particularly APS) also released significant levels of chloride; VES did not. Chloride release appeared to be increased by γ -irradiation. As a result of the low pH chloride-containing environment created by the APS encapsulant, 316L experienced localized corrosion, whereas coupons in Alchemix 4760 and VES did not. Weight loss measurements correlated with visual observations. Gamma-irradiation appeared to increase the degree of corrosion.

KEYWORDS: nuclear waste storage, polymeric encapsulation, pitting corrosion, 316L, stainless steel, γ -irradiation.

Introduction

THE majority of the UK's intermediate-level radioactive waste (ILW) is currently encapsulated in cement grout. However, for some wastes such as reactive metals, conventional grouts may not be suitable due to adverse reactions between the waste and cementitious porewaters. Polymers that

produce a dry low-permeability wasteform are already being used to encapsulate reactive metals as their use can limit corrosion, which could otherwise pose a threat to the stability of cement-based wasteforms (e.g. through swelling and cracking processes). One area of concern with polymeric encapsulants is their long-term chemical stability and the possibility that degradation resulting particularly from irradiation or thermal ageing may release species that enhance the corrosion of waste containers, the majority of which are currently fabricated from stainless steel.

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TABLE 1. Experimental test matrix (14 test cells setup).

Radiation dose (Gy h ⁻¹)	10	10	None	None
Temperature (°C)	80	80	80	80
Solution	DI water	Ca(OH) ₂	DI water	Ca(OH) ₂
APS	✓	✓	✓	✓
Alchemix 4760	✓	✓	✓	✓
VES	✓	✓	✓	✓
No polymer (control)	✓	✓	—	—

This paper describes the results of an experimental study to evaluate the potential for three candidate polymeric encapsulants to cause internal corrosion of stainless steel containers during periods of interim surface storage and under simulated post-closure conditions in a geological disposal facility (GDF). The materials tested in this study were two epoxy resin-based polymers [the APS polymer system, sometimes also referred to as DTS 800 (APS) and Alchemix 4760 (ALC)] and a vinyl-ester styrene, also known as DTS 901 (VES). These materials have been considered, or in some cases are already being used, within the UK nuclear industry as encapsulants for some ILW.

Previous studies have investigated aspects of the mechanical properties and chemical stability of these three materials in conditions of relatively high temperature (80°C) and ionizing radiation (Dawson *et al.*, 2009) and (Dawson, 2010). To the authors' knowledge, little additional relevant information exists to evaluate the likely corrosivity of solutions potentially formed in contact with candidate polymeric materials at elevated temperature and in the presence of ionizing radiation.

Methodology

Sample preparation and set up of immersion tests

The corrosion behaviour of 316L stainless steel in the three encapsulants was studied using immersion tests in aerated saturated Ca(OH)₂ solutions and deionized (DI) water, under γ -irradiated (10 Gy h⁻¹ \pm 20%) and non-irradiated conditions, for eighteen months. Control tests were also performed in which coupons of 316L were immersed in the solutions without the polymer present. All tests were conducted at 80°C (a conservative upper temperature limit for ILW containers). Tests in DI water were carried out to

evaluate the potential effect of aqueous solutions that could form within vented ILW packages due to (1) condensation of moisture during periods of interim above-ground storage; or (2) in the initial (oxic) stages after closure of a GDF in which near-neutral, non-buffered backfill materials are used (Nuclear Decommissioning Authority, 2010). Tests in Ca(OH)₂ were carried out to evaluate (1) the potential for internal corrosion of ILW containers containing cement-based materials (e.g. liners or capping grouts) in contact with polymeric encapsulants; and (2) to evaluate their likely behaviour in the initial (oxic) stages after closure of a GDF employing cement-based backfill materials (Nuclear Decommissioning Authority, 2010).

The matrix of tests conducted is shown in Table 1. Fourteen individual test cells were set up. An illustrative example of how each test cell was assembled is shown in Fig. 1. In brief, 38 mm diameter cylinders of the three polymers were cast (Fig. 1a); 30 mm long individual polymer pucks were then cut from the cylinders and five individual slots (measuring 21 \times 10 \times 2 mm) were machined into each puck. Test specimens of 316L stainless steel measuring 20 \times 10 \times 1.5 mm (five per cell) were placed in the slots in the matrix of each polymer (Fig. 1b), to simulate the formation of crevices between the encapsulants and the waste container. Each of the stainless steel test specimens was labelled using impression stamping. Each sample had a uniform glass bead blasted finish, to replicate the surface finish commonly used in ILW containers.

The polymer pucks were then placed in zirconia crucibles (~40 mm diameter, 75 mm height, volume ~94 cm³) and filled with 50 ml of the desired test solution (i.e. DI water or saturated Ca(OH)₂), covering the polymer matrix and all the steel samples (Fig. 1c). The crucibles were then placed inside two-part glass cells of ~60 mm diameter (Fig. 1d) (crucibles were used to avoid

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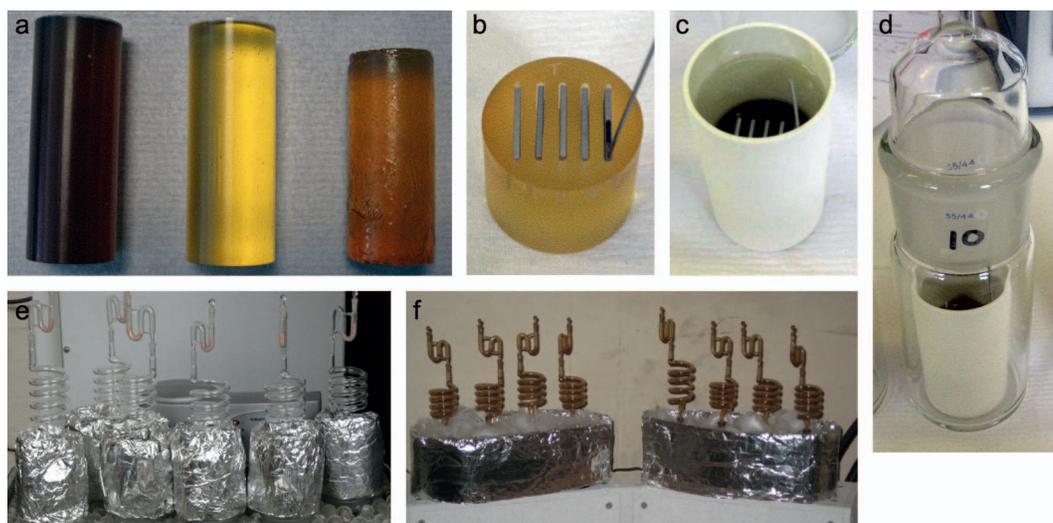


FIG. 1. Experimental set up, showing (a) the candidate encapsulants cast into cylinders; (b) individual pucks machined from the cylinder with slots and steel samples placed into the slots to simulate crevices; (c) pucks transferred into zirconia crucibles and filled with test solution; (d) crucibles transferred into glass cells. The individual glass cells transferred into either (e) an oil bath (non-irradiated), or (f) a heater block (γ -irradiated).

silicate contamination from glass dissolution). Each cell was vented to the atmosphere, to avoid pressure build up. The cells were vented through air-cooled condenser coils to ensure that evaporative losses were minimized. In an attempt to prevent carbonation of the test solutions, each condenser coil was fitted with a U-bend trap filled with granular 'Carbosorb'. Throughout the duration of the study the Carbosorb was changed approximately every two to three months.

Solution analysis and corrosion behaviour

Each of the fourteen test cell solutions was analysed (for chloride) using ion chromatography (IC) after 1, 6, 12 and 18 months. A 30 ml sample of the available 50 ml solution was taken from each solution for the first two sampling campaigns (i.e. after 1 and 6 months) and replaced with an equivalent volume of fresh solution. For subsequent sampling (i.e. after 12 and 18 months) the sampled volume was reduced to 10 ml, to minimize changes in the electrolyte concentration. The pH of the sample was measured immediately on collection, after which the sample was analysed by ion chromatography.

X-ray fluorescence (XRF) was conducted on the three polymers using an Oxford Instruments Twin-X XRF spectrometer, so that a semi-

quantitative estimate could be obtained of the concentrations of chlorine present in the initial unaged, as-received polymers.

The extent of corrosion of the 316L test coupons was assessed using optical microscopy including confocal microscopy where required to quantify corrosion damage. Metal samples were removed from solution and inspected after 6, 12 and 18 months of exposure. Pit depth measurements on selected samples were conducted to quantify the extent of attack.

Following visual inspection, weight loss testing was conducted on each removed sample. Three separate weights were used to calculate the total weight loss due to corrosion of each sample W , using the following equation: $W = M_0 - M_1 + (M_1 - M_2)$, where M_0 is the original weight, M_1 is the weight following a first clean and M_2 is the weight following a second repeat clean. The surfaces of the samples were cleaned to remove corrosion products using dilute nitric acid, as recommended by ASTM standard G1-90, (ASTM International, 1999). Values of M_0 , M_1 and M_2 were measured for each sample using an A&D HM-202EC balance with an instrument resolution of $\pm 2 \times 10^{-5}$ g. Samples were weighed to four decimal places (i.e. 1×10^{-4} g).

Once the eighteen month experimental period had concluded, the remaining solutions were

extracted from each of the test cells and *ex situ* electrochemical measurements (open circuit potential (OCP), and cyclic polarization) were conducted on fresh 316L coupons in selected 'aged' test cell solutions. The six originally DI water test solutions were selected for these measurements because these solutions were expected to be the most corrosive (based on previous visual and weight loss observations). Cyclic potentiodynamic scans were conducted using a Solartron 1280C potentiostat after 300 s at OCP at a scan rate of 0.1667 mV s^{-1} . Electrochemical measurements were collected using a silver/silver chloride reference electrode, and then adjusted to appear against the saturated calomel electrode (SCE) for easier comparison with the wider literature.

Results

Solution analysis

Measurable amounts of chloride were released from the two epoxy resin-based polymers and there appears to have been a small but significant increase in the concentration of chloride released under irradiated conditions compared to non-irradiated conditions (Fig. 2). In 50 ml of solution, the electrolyte containing the irradiated APS encapsulant reached 1900 ppm of chloride at the end of the test. The solution containing the Alchemix 4760 encapsulant reached 700 ppm of chloride at the end of the test (although it should be noted that if the test cells had not been periodically sampled and topped up with stock solution the cumulative concentrations of chloride would probably have been higher). Broadly speaking, the rates of chloride release from the two epoxy polymers remained constant throughout the eighteen month test period. In contrast the VES polymer system leached far lower levels of chloride, typically <25 ppm total, a value comparable with the 'no polymer' controls. It is clear that the release of chloride broadly correlated with the total amount of measured chlorine available within the starting solid polymer measured by XRF: APS 0.78, Alchemix 0.43 and VES 0.23 wt.% chlorine. It is not possible to state the chemical form of the chlorine in the polymers from this analysis.

Figure 3 shows the results of pH measurements carried out over the same time periods. Within one month of immersion and throughout the test duration, all of the DI water test solutions (initial pH value 7.6) reached low, stable pH values (APS and VES <pH 4, whereas Alchemix was around

pH 5). Gamma-irradiation did not appear to significantly affect the pH value of the solutions. The tests in $\text{Ca}(\text{OH})_2$ solutions (initial pH value 12.6) also showed a pH reduction after only one month (particularly the cells containing VES). After the first month, in order to run the tests in conditions simulating a significant buffering capacity of the environment, it was decided to readjust the pH to the initial (nominal) value through the addition (0.4 g) of excess solid $\text{Ca}(\text{OH})_2$, placed beneath the polymer puck within each of the high pH test cells. This, however, was only partly effective in maintaining the nominal pH value in the long term. Measurements carried out on the control samples showed that, in both DI water and $\text{Ca}(\text{OH})_2$, the reduction in pH in the presence of the polymers was partly due to carbonation. The precipitate visible in the $\text{Ca}(\text{OH})_2$ test cells was shown [via X-ray diffraction (XRD) analysis, data not shown] to predominantly contain calcium carbonate (traces of other compounds such as calcium silicate hydroxide hydrate were also detected). Additionally XRD analyses of this precipitate showed the formation of a calcium oxalate, in particular in some of the VES- $\text{Ca}(\text{OH})_2$ test cells, suggesting that oxalic acid was released from VES.

Corrosion performance

No evidence of corrosion was observed on any of the 316L corrosion coupons immersed in the high pH $\text{Ca}(\text{OH})_2$ solutions after eighteen months of exposure, with or without γ -irradiation (Fig. 4, left hand side images), or in the corresponding 'no polymer' control cells with $\text{Ca}(\text{OH})_2$ solution. The top six images on the left hand side of Fig. 4 show the front and back of the 316L coupons exposed to the three polymers in saturated $\text{Ca}(\text{OH})_2$ solution, whereas the lower two left hand side images show the appearance of the 'no polymer' control samples. The precipitate visible on the samples is likely to have been the solid $\text{Ca}(\text{OH})_2$ that was added to the test cells. Weight loss data (Table 2) indicated no loss of material in these conditions up to eighteen months of exposure, confirming the visual observations.

In contrast, significant corrosion developed on the 316L coupon in contact with the APS polymer in DI water after eighteen months exposure, most extensively in irradiated conditions (as shown in Fig. 4, top right images) and also, but to a lesser extent, in non-irradiated conditions (not shown).

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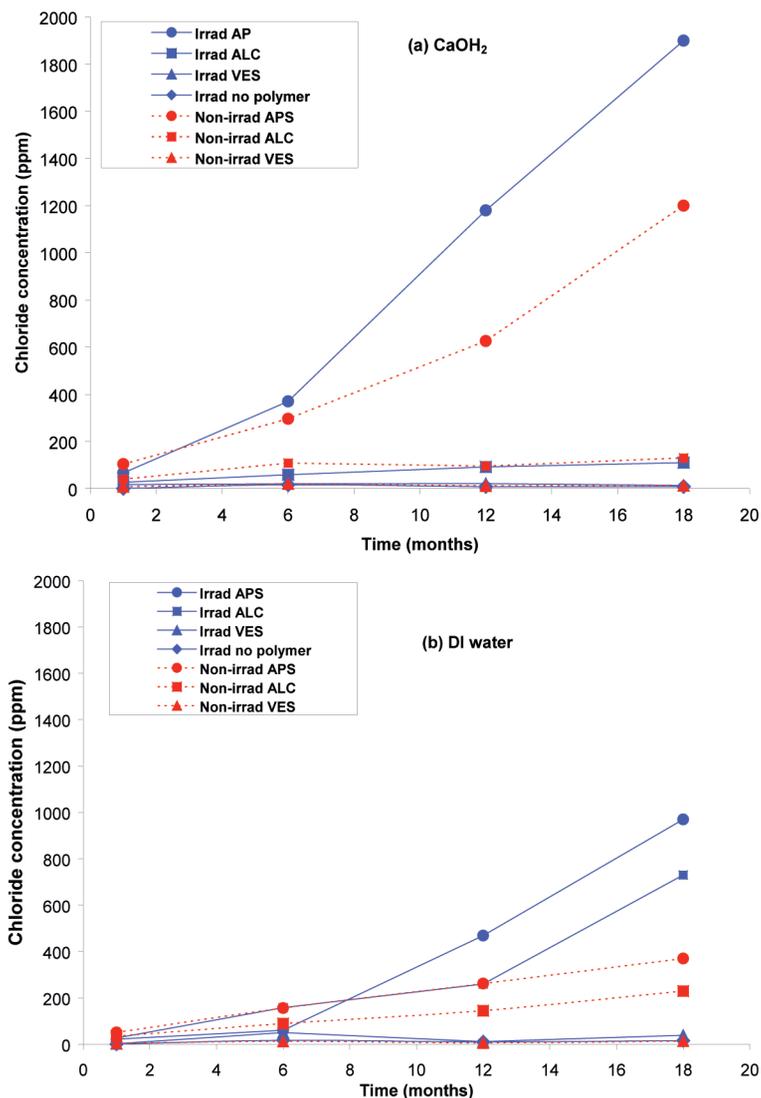


FIG. 2. Chloride concentration (IC) of test solutions after 1, 6, 12 and 18 months exposure to APS, Alchemix, VES and no-polymer control cell at 80°C, with and without γ -irradiation: (a) Ca(OH)₂ solution and (b) DI water.

The 316L samples in contact with the other two candidate polymer systems (Alchemix and VES) and the no-polymer control in DI water experienced relatively little attack (Fig. 4, right hand side lower three images). Visual observations and weight loss measurements on samples immersed for 6 and 12 months (Table 2) indicated similar behaviour, with the degree of corrosion observed increasing in samples in contact with APS exposed for longer periods.

Corrosion damage experienced by the samples contained within APS was initially observed to develop predominantly along the upper region of the samples, in the form of pits with relatively large dimensions (some as large as ~500–750 μm diameter). Figure 5 shows the most attacked 316L sample observed in the current study. This sample had been in contact with APS and immersed in DI water for eighteen months under γ -irradiation. It did not contain the deepest pit, but did possess by

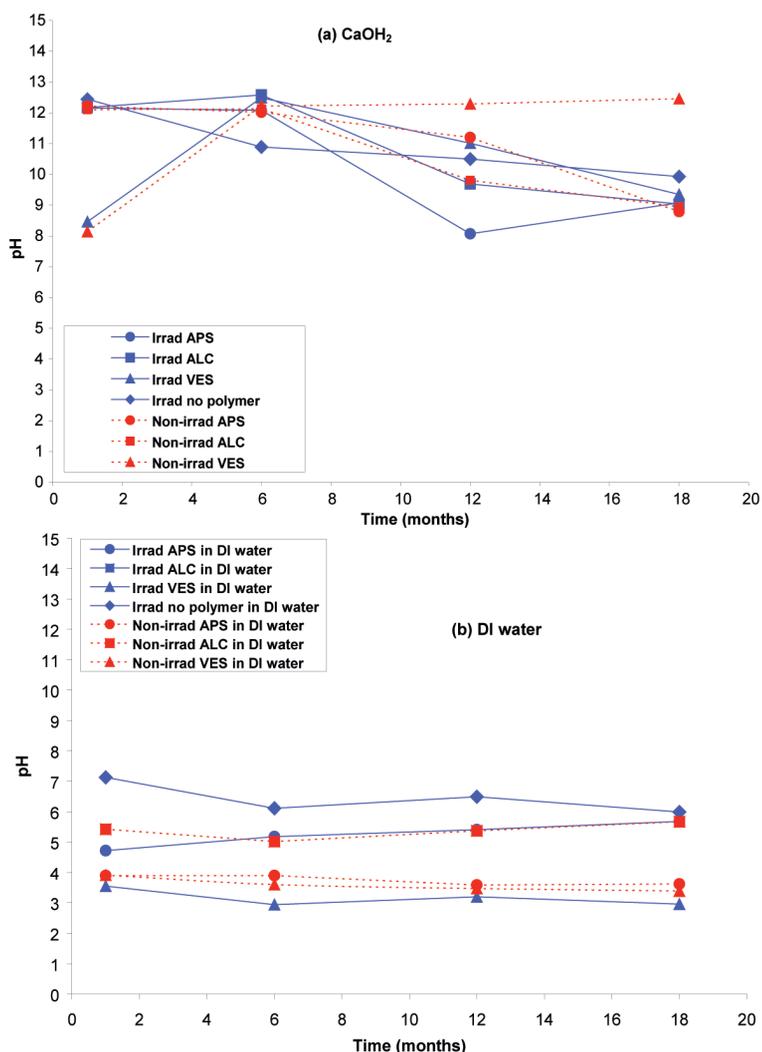


FIG. 3. The pH of test solutions after 1, 6, 12 and 18 months exposure to APS, Alchemix, VES and no-polymer control cell at 80°C, with and without γ -irradiation: (a) Ca(OH)₂ solution (initial pH value 12.6) and (b) DI water¹ (initial pH value 7.6).

¹ A spurious data point was observed in tests in DI water (6 months γ -irradiated APS). This was due to the cell leaking, allowing test solution to escape out of the cell through evaporation. The cell was quickly refilled with DI water, but species (still contained in the crucible) would have taken time to redissolve into the replaced water, hence pH measured immediately after refilling was close to that of DI water.

far the highest pit density and clear evidence of pitting on areas of the sample that were situated deep within the crevice forming slot (as opposed to predominantly along the exposed top edge of the sample). Weight loss testing confirmed that it had experienced the greatest amount of total dissolution.

These measurements suggest that exposure to γ -irradiation at a dose rate of $\sim 10 \text{ Gy h}^{-1}$ increases the amount of corrosion experienced by 316L in contact with an unbuffered oxic solution that may form in contact with chloride-containing polymers (particularly APS). Weight loss testing (Table 2) confirmed the visual

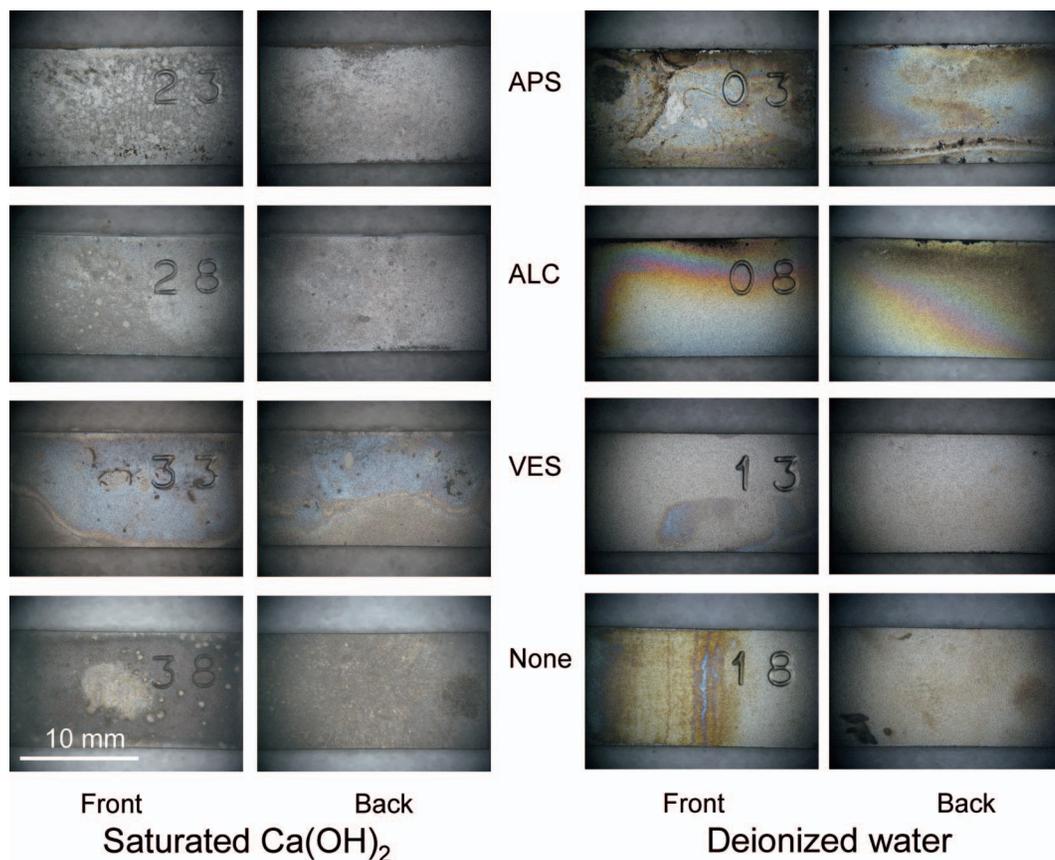


FIG. 4. The 316L corrosion coupons after 18 months γ -irradiation (10 Gy h^{-1}) at 80°C in saturated $\text{Ca}(\text{OH})_2$ (left side) and initially DI water (right side).

observations and showed that the most corrosive conditions developed in the DI water test cells that contained APS in the presence of γ -irradiation.

Ex situ electrochemical measurements

Figure 6a shows cyclic potentiodynamic polarization curves measured on fresh coupons immersed in the six aged (originally DI water) test solutions. On the forward side of the sweep (increasing potential from the OCP), these plots show a passive region followed by a sharp increase in current density associated with the onset of localized corrosion. To compare the anodic reactivity of 316L in the various aged test solutions, a nominal 'breakdown potential' (the potential at which the current density reaches $10 \mu\text{A cm}^{-2}$, i.e. stable pitting occurs) has been taken from the potentiodynamic plots (shown in

Fig. 6a and plotted in Fig. 6b). Repassivation potentials (the potential at which the protective oxide film reforms) measured on the reverse sweep (decreasing potential) in the same manner are also shown. Examination of the samples after anodic polarization indicated that the breakdown was due to pitting.

The 316L samples tested in solutions created from the APS encapsulant showed the highest corrosivity (lowest breakdown potentials, $\sim 0.4 \text{ V}_{\text{SCE}}$). Solutions from the Alchemix 4760 and VES tests were less corrosive, with breakdown potentials of $\sim 0.6\text{--}0.7 \text{ V}_{\text{SCE}}$. With the exception of the solution generated from VES, there did not appear to be a significant difference in terms of breakdown potentials between solutions generated under irradiated and non-irradiated conditions. It is important to bear in mind however that electrochemical tests were conducted about one month after the cells had

TABLE 2. Weight loss measurements for 316L stainless steel test coupons removed after 6, 12 and 18 months exposure to DI water and Ca(OH)₂ solutions in contact with APS, ALC and VES at 80°C. Weight losses greater than 0.01 g cm⁻² are shown in bold. Note that a loss of 0.01 g cm⁻² over 12 months is equivalent to a general corrosion rate of 12.5 μm y⁻¹ (assuming a stainless steel density of 7.99 g cm⁻³).

Solution and polymer	Weight loss (g cm ⁻²)		
	6 months	12 months	18 months
Irrad DI water + APS	0.0449	0.0673	0.0776
Irrad DI water + ALC	0.0061	-0.0020	-0.0041
Irrad DI water + VES	0.0020	0.0245	0.0082
Irrad DI water	0.0000	-0.0020	0.0020
Irrad Ca(OH) ₂ + APS	0.0000	0.0041	0.0041
Irrad Ca(OH) ₂ + ALC	-0.0020	0.0061	0.0000
Irrad Ca(OH) ₂ + VES	0.0020	0.0041	0.0000
Irrad Ca(OH) ₂	0.0020	0.0082	0.0041
Non-irrad DI water + APS	0.0041	0.0061	0.0122
Non-irrad DI water + ALC	0.0020	0.0000	0.0061
Non-irrad DI water + VES	0.0000	0.0041	0.0041
Non-irrad Ca(OH) ₂ + APS	0.0020	0.0041	0.0020
Non-irrad Ca(OH) ₂ + ALC	0.0020	0.0020	0.0041
Non-irrad Ca(OH) ₂ + VES	0.0020	0.0061	0.0041

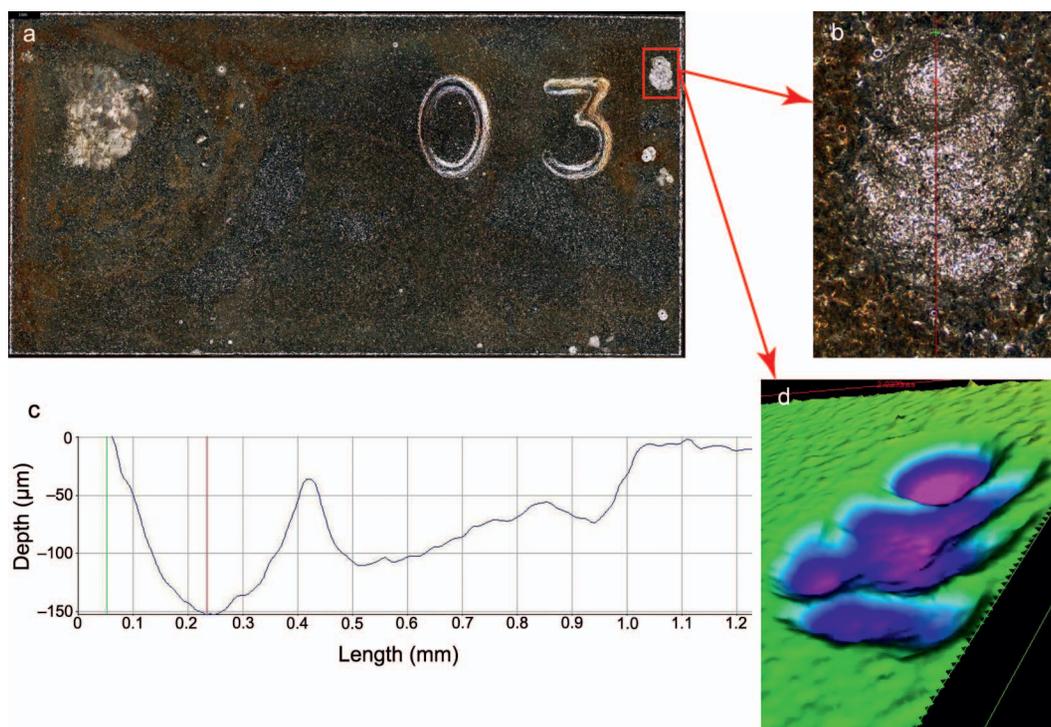


FIG. 5. An example of pitting corrosion experienced by 316L encapsulated in APS and immersed for 18 months in initially DI water in the presence of γ -radiation (10 Gy h^{-1}) at 80°C. (a) optical image of the front side of the whole coupon; (b) enlarged optical image showing the deepest pit; (c) surface profile across the width (as indicated in image (b)) of the pit; (d) the same pit area in 3D.

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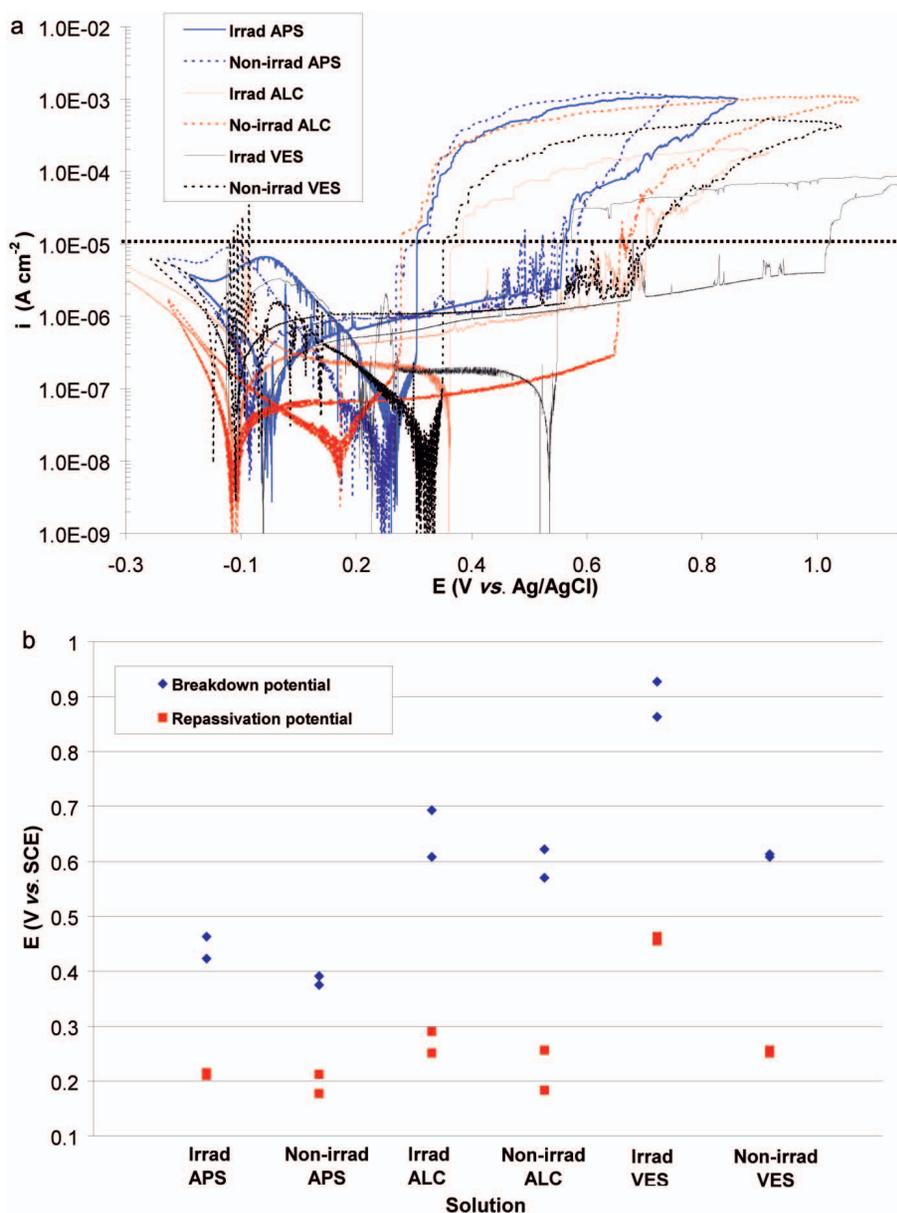


FIG. 6. Electrochemical measurements showing (a) cyclic potentiodynamic polarization (vs. Ag/AgCl) on fresh 316L coupons (sweep rate 0.166 mV s⁻¹) in DI water solution after ~18 months exposure to APS, Alchemix and VES at 80°C; and (b) breakdown and repassivation potentials (converted to vs. SCE) determined from cyclic polarization (i.e. potentials when $i = 10^{-5}$ A cm⁻² on the forward and reverse scans).

been removed from the irradiation facility. Therefore any unstable, short-lived radiolysis products present *in situ* would probably no longer have been present in the solutions.

Discussion

Chloride ions in a low pH solution are a well known potential cause of localized corrosion of stainless steel (Sedriks, 1996). These conditions

were found to arise, when 316L corrosion coupons were 'encapsulated' in APS, an epoxy-based polymer system, and immersed in unbuffered DI water. Such exposure conditions could potentially arise between the encapsulant and the container wall due to the accumulation of condensation during interim storage of vented packages, or if vented packages containing polymeric encapsulants were to be disposed of without appropriate alkaline buffering in a GDF which later became saturated with groundwater. The species responsible for the pH reduction observed in the DI water experiments and, to a lesser extent the $\text{Ca}(\text{OH})_2$ cells, are likely to have been carboxylic acids, which can be generated by the irradiation of polymers in aqueous solution (Dawson *et al.*, 2009). High concentrations of chloride ions were found to be leached from the APS epoxy resin and to a lesser extent from Alchemix 4760. Importantly none of the three candidate polymers (the two epoxy resins or VES) tested in this work are expected to contain chlorine in their molecular structure. However, as discussed by Dawson *et al.* (2009), epoxy resins such as APS and Alchemix 4760 are manufactured from a wide range of different compounds. Many epoxy resin formulations are based on production of the diglycidyl ether of bisphenol A (DGEBA) by the reaction of epichlorohydrin ($\text{C}_3\text{H}_5\text{ClO}$) and bisphenol A ($\text{C}_{15}\text{H}_{16}\text{O}_2$). It is therefore possible that chloride ions could remain in the polymer as a by-product of manufacture, or even originate from chloride contamination of the epichlorohydrin used in the manufacturing process. In addition to free chloride from polymerization or contaminated starting materials, the production of commercial epoxy resins commonly uses excess epichlorohydrin (Bikales, 1986). If unreacted molecules of this compound remain in the polymer after production, there may be further potential for the generation and release of chloride ions in any environment in contact with the polymer.

The observations made in this study indicate that the chloride released from the two epoxy-based candidate polymeric encapsulants, together with the acidic conditions generated by the release of organic acids, increase the potential for corrosion of stainless steel waste containers exposed internally to unbuffered, oxidic, near-neutral solutions. It is important however to understand whether or not the increased corrosion experienced by the irradiated 316L coupons in DI water in contact with the APS, compared to the

non-irradiated coupons, was solely due to the fact that higher chloride concentrations were leached into the solutions, or whether exposure to ionizing radiation also contributed to the increased corrosion rate. The chloride release from the irradiated APS was about a factor of two higher than that from the non-irradiated polymer during all exposure periods suggesting that ionizing radiation caused an increase in the rate of chloride release, which subsequently led to an increased corrosion rate. It is also possible that the corrosion rate was further enhanced by the presence of reactive radiolysis products; this possibility is discussed below.

Visual observations of samples immersed in solutions indicated that pitting corrosion is possible at the levels of chloride released from some encapsulants under the conditions in this study. Analysis of the literature suggests that the amount of chloride required at 60°C and at a pH of ~4 to induce pitting corrosion of 316L is greater than 1000 ppm (Sedriks, 1996). This value is significantly higher than any critical chloride concentration threshold observed to cause pitting of 316L in this study. It is acknowledged that the amount of chloride required to develop pitting at 80°C may be lower than this 1000 ppm value but it is still thought likely to be higher than some of the values observed in this study (for example, in irradiated samples pitting was observed within six months, at which time the chloride level measured in the system was <100 ppm, see Fig. 2). *Ex situ* electrochemical measurements carried out in aged solutions in the absence of radiation, moreover, indicated breakdown potentials significantly higher than the OCP measured at the beginning of the immersion (during passivity). These observations suggest that there may be an effect of radiation in increasing the OCP during *in situ* measurements (i.e. when the test cells were being irradiated) that would not be present in *ex situ* measurements conducted some time (~1 month) after the cells were removed from the γ -irradiation facility.

Gamma-irradiation has been shown to increase the OCP of a metal, due to the formation of oxidizing species (Donohoe, 2009). It has been demonstrated (Marsh *et al.*, 1986) that at dose rates of 10–200 Gy h^{-1} the OCP of stainless steel in solution is strongly elevated (by some 0.22–0.4 V) by exposure to γ -irradiation. The increase in potential experienced during irradiation in this study may have been sufficient to increase the OCP above the breakdown potential, thus enhancing the likelihood of localized

corrosion. This could also explain the observation that pitting corrosion occurred on 316L encapsulated in APS after six months of irradiation in initially DI water (observation suggested by weight loss data) at chloride concentrations <100 ppm (Fig. 2), which is far below the levels expected to be required to induce pitting in the absence of radiation. The effect of irradiation on corrosion is likely to be associated with water radiolysis producing oxidizing, short-lived radicals and hydrogen peroxide rather than by any modification of the metal's passive film. This idea is supported by the fact that the observed increase in corrosion potential has been shown to remain in non-irradiated steels exposed to previously irradiated solution within timescales compatible with the expected survival of hydrogen peroxide in the system (i.e. shorter than those tested in this study) (Donohoe, 2009). In fact, chemical additions of hydrogen peroxide to non-irradiated waters have been shown to produce broadly the same effect as γ -irradiation on the corrosion potential (Herbert *et al.*, 1994).

Conclusions

The main conclusions from this study are as follows:

(1) Polymeric encapsulants are unlikely to cause corrosion of stainless steel ILW containers if in contact with alkaline materials (e.g. cement) in sufficient amounts to buffer the pH of any aqueous phase to high values.

(2) A potential for internal corrosion exists for polymers containing chloride (e.g. APS) if solutions with limited buffering capacity form between the encapsulant and the container (e.g. due to the accumulation of condensation during interim storage of vented packages or if packages containing polymeric encapsulants were to be packaged and/or disposed of without appropriate pH buffering). Such conditions could arise in a non-cementitious backfilled and saturated GDF.

(3) The two epoxy polymers tested (APS and Alchemix) released higher chloride levels than the vinyl-ester styrene (VES); APS released the most chloride. There was a small but significant increase in the chloride released under irradiated conditions compared to non-irradiated conditions.

(4) Irradiation appeared to increase the degree of corrosion experienced by 316L coupons immersed in DI water in contact with APS. There are some indications that this effect may be associated with the presence of short-lived

radiolysis products rather than solely to the increase in the amount of chloride released.

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