

Evaluation of Pitting Penetration Associated with Steel Exterior of Hanford Tanks

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ABSTRACT

Radioactive and chemically hazardous wastes are stored at the Hanford site in underground double-shell tanks (DSTs) constructed of carbon steel. The corrosion management of these tanks has largely focused on the complex waste chemistries that reside within the interiors of the primary tanks. More recently, attention has been given to the corrosion that has been found on the exterior of the secondary liners of the DSTs. The cause of the external corrosion seems to be related to the intrusion and accumulation of groundwater in the tertiary leak detection systems, which exist under the concrete foundations of the DSTs. The external corrosion has led to significant wall-loss (up to 70% in one of the tanks), which has occurred in a localized manner (broad pitting). In addition, site measurements have indicated that the most significant areas of wall-loss are aligned with the slots (drain channels) of the concrete foundation.

Experiments were conducted to assess the penetration rates that could be associated with the external corrosion of the secondary liners. Carbon steel specimens were affixed to slotted concrete blocks and exposed to a synthetic groundwater solution that was periodically raised and lowered in the test vessel to create alternate immersion conditions. Pitting penetration rates were determined by measuring the maximum depth of localized attack as a function of exposure time in the groundwater environment. The penetration rates decreased with time and appeared to follow a power-law behavior. Also, it was found that the penetration rates of the concrete-contacted regions of the specimens were generally lower than the rates of the boldly exposed or slotted regions.

Keywords: Hanford, carbon steel, external corrosion, pitting, concrete.

INTRODUCTION

The Hanford site contains approximately 55 million gallons (2.08×10^8 liters) of radioactive and chemically hazardous wastes arising from weapons production, beginning with World War II and continuing through

the Cold War era. The wastes are stored in 177 carbon steel underground storage tanks, of which 149 are single-shell tanks (SSTs) and the remaining are double-shell tanks (DSTs). Historically, tank failures have been associated with the SSTs. However, in 2012, a failure was encountered for the first time in one of the DSTs: Tank AY-102. The failure of AY-102 occurred from internal corrosion of the primary liner,¹ which allowed the waste to leak into the annular space between the primary liner and the secondary liner. The waste never reached the surrounding soils due to the containment provided by the secondary liner.

Although the failure of AY-102 was related to the primary liner of the tank, one of the resulting recommendations from the failure investigation was to perform ultrasonic testing (UT) on the secondary liners as part of the core inspection practices for the DSTs. The need for routine inspection is further underscored by the fact that there is a reported history of water ingress and accumulation in the leak detection pit (LDP) systems, which reside on the external side of the secondary liners.² The LDPs are considered tertiary containment systems and are designed to collect any liquid waste draining from beneath the tanks in the event of a secondary liner breach. The LDP designs vary depending on the tank farm but share the common feature of having drain slots that channel liquid into a leak detection well or pit. The drain slots for the LDPs are provided by the DST foundations, which are slotted concrete pads. UT scans have indicated that wall-thinning of the secondary liner tends to align with the slots of the concrete foundation.³

According to a 2019 document⁴, UT scans of the secondary liner have been performed on 15 of the 27 DSTs that are active. Even though these scans have been limited to the annulus floor of the DSTs, 13 have shown reportable wall loss (loss > 10% of nominal thickness). For Tank AP-102, the wall-loss was found to be as high as 70% in a localized area where pit-like features were reported. When this area of concern was reexamined after 5 years, the UT results indicated that the wall-loss had not increased.⁵ It was unclear whether environmental changes (i.e., less moisture) within the LDP system had restrained the wall-loss from increasing or whether it was due to natural stifling of localized corrosion growth.

In a previous study⁶ that involved laboratory testing under simulated LDP conditions, it was found that localized corrosion could easily initiate on carbon steel, even for specimens that were only exposed to humid/vapor phase conditions. The study also showed that the localized corrosion rates of carbon steel could average as high as 1.78 mm/yr (70 mils per year) when making galvanic current measurements using a multi-electrode array (MEA). Although the penetration rates associated with the MEA were considered to be very high, it was presumed to be related to the relatively short time scale of the experiments (5 weeks).

One of the main objectives of the research described in this paper was to demonstrate that, even though localized corrosion occurs under LDP-like conditions, the rate tends to decrease over longer exposure times. In this work, carbon steel specimens were affixed to concrete blocks and exposed to a simulated LDP environment for up to 210 days. The pitting penetration rates were determined by measuring the maximum depth of localized attack as a function of exposure time. The penetration rates were evaluated on concrete-contacted regions of the steel specimens as well as on areas that were boldly exposed to the environment.

EXPERIMENTAL

Steel Compositions and Test Specimens

American Association of Railways Tank Car (AAR TC) 128 Grade B steel⁽¹⁾ (TC-128) was used in the experimental work to simulate the legacy steel used in the construction of the double-shell tanks. TC-128

⁽¹⁾ This steel does not have a corresponding UNS number.

steel is similar in composition to the UNS K02401 Grade 60 steel used in the Hanford AY-101 and AY-102 tanks. The chemical composition of TC-128 steel is shown in Table 1. Prismatic test specimens (25.4 mm x 12.7 mm x 12.7 mm) were fabricated from plates of the TC-128 steel. The exposed surfaces of the steel specimens were polished to a 600-grit finish and then degreased with acetone prior to testing.

Table 1: Chemical composition of AAR TC 128 Grade B steel (TC-128 steel)

Steel	Element, weight %									
	C	Mn	P	S	Si	Cu	Cr	Ni	V	Fe
TC-128	0.21	1.03	0.01	0.01	0.06	0.04	0.05	0.02	0.07	Bal.

Concrete Material

A vendor that specializes in concrete research and testing was commissioned to prepare concrete cylinders in conformance with the general specifications of the structural concrete used in the DST foundations. The details and procedures regarding the preparation of the cast concrete cylinders are provided elsewhere.⁶ The concrete cylinders were machined into slotted concrete blocks that were incorporated into steel-concrete test assemblies. Figure 1 contains photographs of the concrete block that was used in the test assemblies. The purpose of the machined slot in the concrete block was to simulate the drain channels of the DST foundation. The approximate dimensions of the slot were 6 mm (width) x 6 mm (depth).

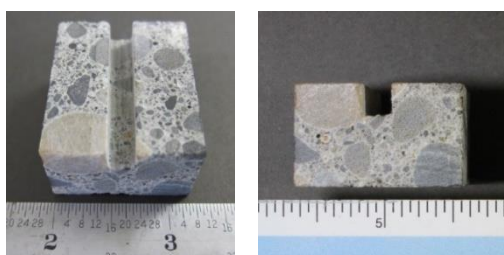


Figure 1: Photograph of slotted concrete block.

Steel-concrete Assemblies

Figure 2 contains a photograph and schematic of the steel-concrete assembly that was used in the testing. The assembly consisted of two steel specimens that were clamped against a slotted concrete block. The steel specimens were partially masked with a peelable stop-off lacquer to limit the corrosion to two sides or surfaces of the specimen. As shown in the figure, these surfaces were designated as: (1) vertical surface and (2) concrete-facing surface. The vertical surface was oriented perpendicular to the solution level while the concrete-facing surface was parallel to the solution level. In each assembly, the concrete-facing surface of the specimen was pressed flat against the concrete block and centered along the slot. The approximate area of each surface was 3.3 cm².

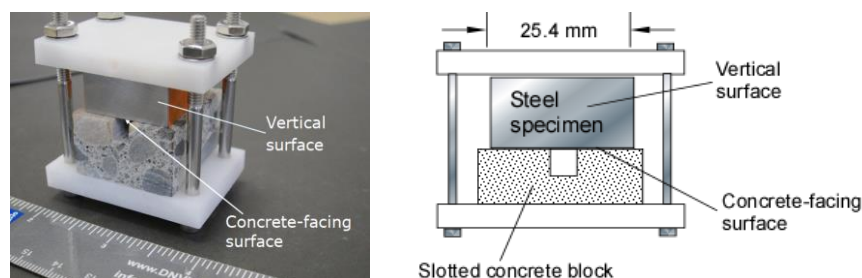


Figure 2: Photograph (left) and schematic (right) of steel-concrete assembly.

Simulated Groundwater Composition

Analyses of groundwater samples that were collected at the Hanford site indicate that the groundwater contains low concentrations of ionic species and has a slightly alkaline pH (7.9 to 8.4).⁷ According to the analyses, bicarbonate is the dominate species, but other prominent ions include calcium, sodium, sulfate, chloride, and nitrate. None of the analyses of groundwater samples from the site indicated the presence of nitrite, which acts as a corrosion inhibitor toward carbon steel.

Table 2 contains the chemical composition of the groundwater simulant that was used for corrosion testing. The groundwater simulant was based on the chemistry of the groundwater samples that were collected at the Hanford site. Accordingly, the groundwater simulant has a pH near 8 due to low concentrations of bicarbonate.

Table 2: Chemical composition of groundwater simulant.

Source Chemical	Concentration (mol/L)
NaHCO_3	1.75×10^{-3}
Ca(OH)_2	1.50×10^{-3}
KNO_3	2.40×10^{-4}
$\text{Fe}_2(\text{SO}_4)_3$	6.25×10^{-4}
FeCl_3	7.67×10^{-5}
$\text{Sr(NO}_3)_2$	2.87×10^{-6}
$\text{Na}_2\text{SiO}_3 \cdot 9\text{H}_2\text{O}$	6.00×10^{-4}
$\text{MgCl}_2 \cdot 6\text{H}_2\text{O}$	3.10×10^{-4}
$\text{C}_2\text{H}_4\text{O}_2$	3.00×10^{-4}
Measured pH at 45°C	8.3

Experimental Procedure for Corrosion Evaluations

A schematic of the experimental setup that was used for alternate immersion and vapor phase corrosion testing is shown in Figure 3. The test setup consisted of a solution reservoir and a peristaltic pump, which allowed the solution level to be raised inside the primary vessel when the pump was active. The specimens were suspended from a sample rack that was designed to create three levels or “zones” within the primary vessel. Each zone was associated with a specific type of exposure condition: the specimens in Zone 1 were exposed to alternate-immersion conditions (1-hr soak per day); the specimens in Zone 2 were briefly pre-soaked in the simulant and then restricted to vapor phase exposure; the specimens in Zone 3 were exposed to the vapor phase without pre-soaking. The pump was programed to power-on for 1 hour of each day. When the pump was operating, the solution level increased to slightly above the specimens in Zone 1, which were positioned about 2 inches above the stagnant solution level. Under stagnant conditions (pump-off), the solution volume inside the primary vessel was around 2 liters and the solution volume inside the reservoir was approximately 4 liters. The solution inside the primary vessel and reservoir were both controlled at 45°C using heating bands, thermocouples, and temperature controllers. The test temperature of 45°C was selected based on the reported temperature range (30 to 45°C) beneath the waste tanks at the site.

The steel specimens were removed from the test vessel after the following exposure periods: (1) 28 days, (2) 56 days, (3) 98 days, and (4) 210 days. Twenty-four steel specimens were exposed and two specimens were removed from each zone at each exposure period. After removal, the specimens were cleaned with an inhibited acid solution that consisted of hydrochloric acid and a corrosion inhibitor. The specimens were then evaluated for weight-loss using an analytical balance capable of reading to 0.1 mg.