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POTENTIAL FOR HYDROGEN GENERATION AND EMBRITTLEMENT OF PRESTRESSING STEEL IN GALVANIZED PIPE VOIDED PILE

submitted to

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BACKGROUND

The Florida Department of Transportation (FDOT) is considering that galvanized pipe be employed in fabrication of prestressed concrete voided piles for marine bridge substructures. In evaluating the appropriateness of doing this, consideration has been given to the possibility of hydrogen generation and embrittlement of the prestressing strand as a consequence of galvanic interaction between the strand and pipe. Occurrence of hydrogen could arise because 1) the two components are most likely in electrical contact, 2) the galvanized zinc layer is electrochemically active to the prestressing steel such that the cathodic hydrogen reaction will occur at the latter component, and 3) concrete, particularly when it is plastic, serves as an electrolyte. Any hydrogen generation raises the possibility of embrittlement of the strand because of its high strength.

OBJECTIVE

The purpose of this study was to investigate the extent to which, if at all, hydrogen is generated at the strand surface of prestressed concrete voided piles that utilize galvanized pipe and project the likelihood that this could cause embrittlement. To accomplish this, a set of experiments were performed as described below.

EXPERIMENTAL PROCEDURE

Six 4” diameter by 8” high concrete cylinders were fabricated using a 0.47 water-to-cement ratio concrete. The mold for three of the cylinders was a commercial plastic container for casting concrete, whereas a section of galvanized pipe served as the circumference for the remaining three. Immediately after placing the concrete, a 10.5” length of 0.205” diameter central straight wire from a seven wire prestressing strand was positioned at the axis of each cylinder to a depth of approximately 6.5”. For the galvanized pipe specimens, an electrical connection was made between the wire and pipe immediately after positioning the wire. Also, a small diameter section of Tygon tube was partially embedded in the concrete adjacent to the steel wire. This was subsequently filled with agar gel containing $NaNO_3$, and a Calomel reference electrode was subsequently positioned upon this for potential measurements. It was intended that this specimen type would simulate the materials and electrochemical processes of an actual prestressed pile that utilizes galvanized pipe to provide the void.

Subsequent to specimen fabrication, Saran wrap was placed about the exposed cylinder top to minimize water evaporation. This wrap was removed after 24 hours, and the specimens were transferred to a 100 percent relative humidity chamber. Measurement of polarized strand and galvanized pipe potential were routinely made beginning as soon as practical after fabrication (within several minutes). Galvanic current was also measured by connecting the lead from each component (prestressing wire and galvanized pipe) to a zero resistance ammeter and momentarily disconnecting the short between these two components.

RESULTS AND DISCUSSION

Figure 1 shows a plot of potential versus time after casting for the six cylinders. This reveals that from the outset potential of the galvanized pipe specimens was more negative than for the plastic cylinder ones. Of particular concern is that instances of extremely negative potentials were recorded in the first several days. Figure 2 shows an expanded scale plot of potential during this early period for the galvanized pipe specimens. These data raise concern since prestressing steel has been shown to become more susceptible to hydrogen embrittlement as potential is made progressively more negative than -0.90 V_{SCE}.[1,2]

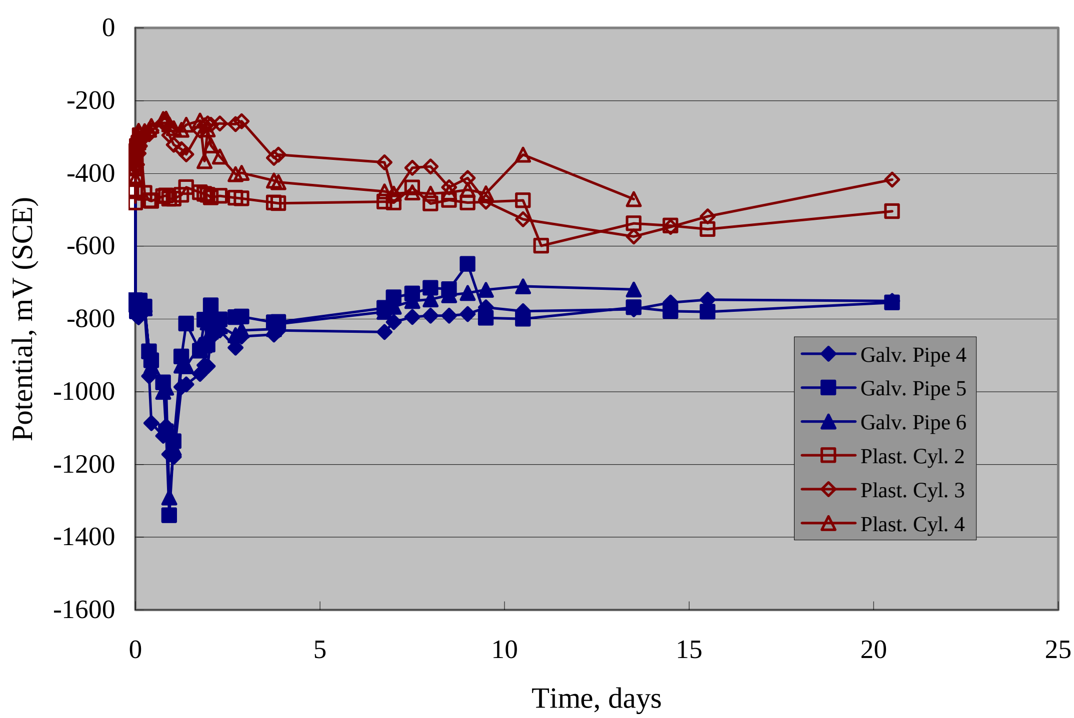

Figure 1: Potential versus time (after pouring) for prestressing wire in concrete cylinders.

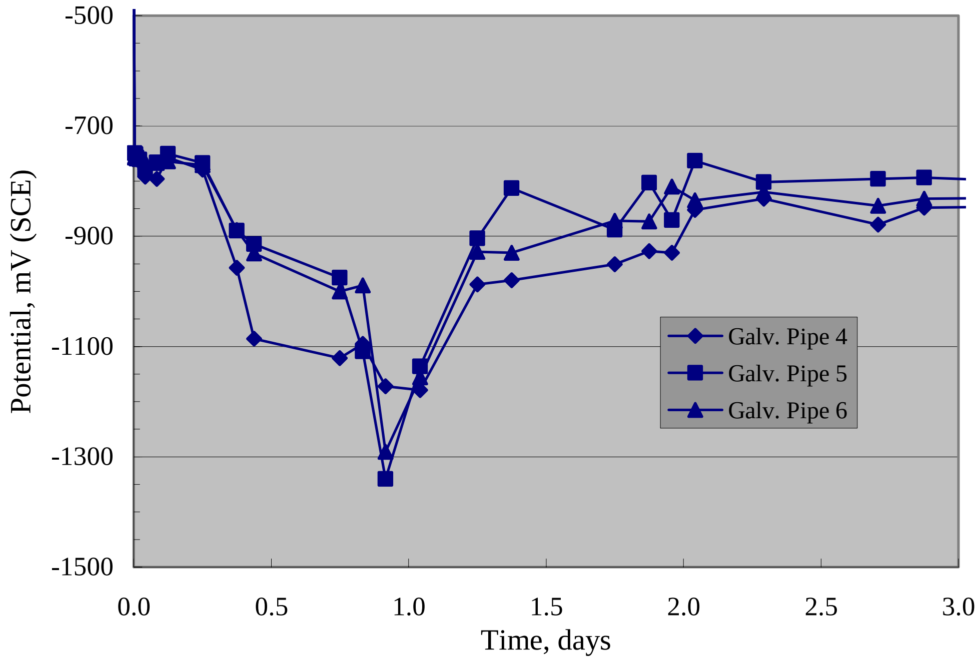

Figure 2: Potential data during the first three days of exposure.

Figure 3, on the other hand, presents the companion current density data for the galvanized pipe specimens as a function of time (no galvanic current is generated for the plastic cylinder encased specimens). This reveals current density to be more than an order of magnitude higher during the first several days after pouring, at which time potential was negative to -0.90 V_{SCE} (see Figures 1 and 2), than for the long-term baseline value. Figure 4 shows an expanded time scale

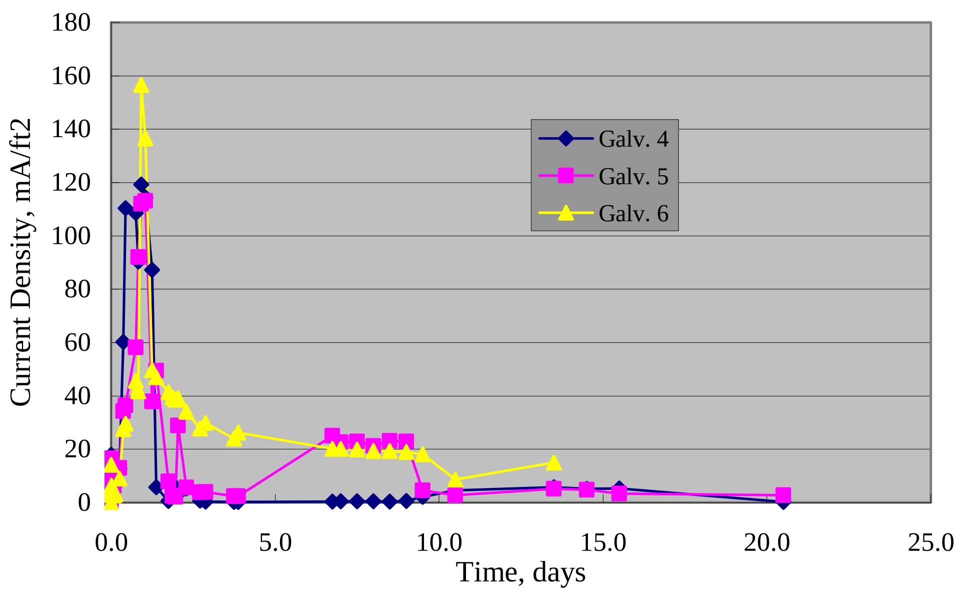

Figure 3: Current density data for the galvanized pipe cylinder specimens.

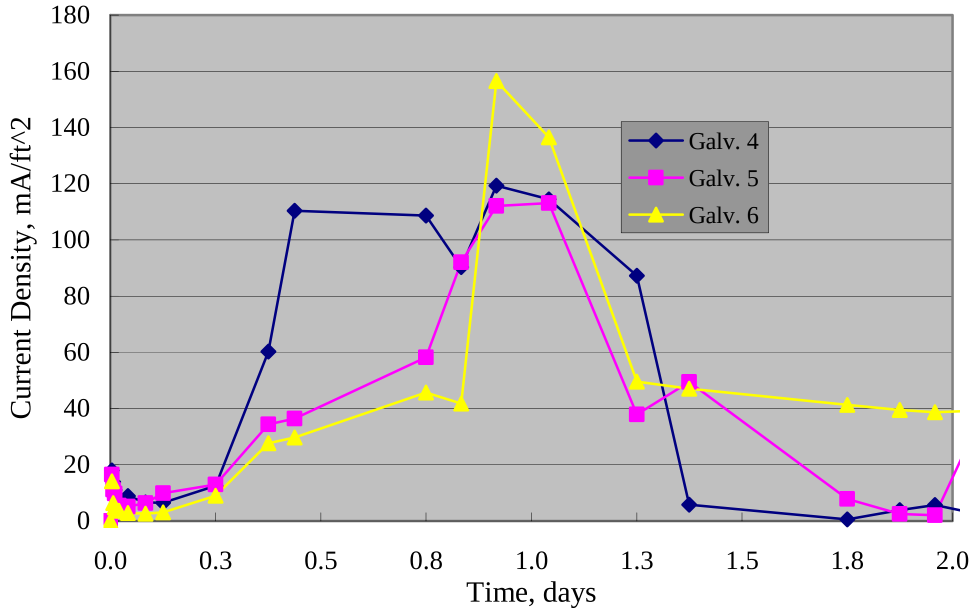

Figure 4: Expanded scale plot of the current density data.

plot of current density during this early period. The baseline or long-term current density, which is several mA/ft^2, is indicative of oxygen reduction, whereas higher values during the time that potential was negative to -0.90 V_{SCE} reflect hydrogen reduction.

To better understand the implications of the high current and the associated hydrogen that was generated, a calculation was made, first, of the Amp-hours corresponding to the high current period and, second, of the hydrogen that was generated. The first parameter (Amp-hours) was calculated as the area under the current density – time curve for the period that current density was high and the latter from Faraday's law. The results are shown in Table 1.

Enos et al. reported that the threshold hydrogen concentration for embrittlement of

Table 1: Calculation results of total Amp-hours for hydrogen generation and the mols of hydrogen generated per unit steel volume.

Galv. 4	Galv. 5	Galv. 6
Total A-hrs		
2.592	4.622	0.035
Mols H per cm^3 steel		
7.06E-02	1.26E-01	9.64E-04

prestressing steel is $2*10^{-7}$ mols/cm^3.[3] Table 2 shows that the hydrogen generated for the present galvanized specimens (Table 1) exceeded this threshold by orders of magnitude. This is an overestimate, however, because not all of the hydrogen would have entered the steel. Nonetheless, the data point out a very real possibility of embrittlement.

Table 2: Factor by which the embrittlement threshold hydrogen concentration was exceeded for the three galvanized pipe specimens.

Galv. 4	Galv. 5	Galv. 6
3.53E+05	6.30E+05	4.82E+03

One of each of the two core types was fractured open at age 22 days, at which time pH measurements were taken on the fresh concrete adjacent to the steel wire using a color indicator and the concrete microstructure was examined. The pH for both specimen types was approximately 13, and no discernable difference in void size or density was apparent in the concrete using low power light microscopy. It can be reasoned that significant hydrogen generation only occurred during the time that potential was negative to -0.90 V_{SCE} (approximately the initial two days after pouring, Figure 2). This was in response to pH being higher than the above measured value when the concrete was fresh and the fact that this activated the galvanized zinc layer to potentials as negative as -1.34 V_{SCE} (Figure 2).

CONCLUSION

The possibility of hydrogen embrittlement of prestressing strand in prestressed concrete voided piles fabricated using galvanized pipe cannot be discounted. Recognizing that alternative materials to galvanized pipe are available and that these have proven satisfactory, it is recommended that galvanized pipe not be used in this application.

BIBLIOGRAPHY

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[3] D.G. Enos, A.J. Williams, G.G. Clemena, and J.R. Scully, *Corrosion*, Vol. 54, 1998, p. 389.