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Original Article

Cathodic polarization behavior of the structural steel wires under different prestressing conditions

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ABSTRACT

Cold-drawn structural steel wires prestressed to different levels and cathodically polarized at various potentials were investigated using electrochemical techniques and slow strain rate tests. The potentiodynamic polarization revealed that prestressing enhances the active anodic dissolution of the structural steel wires. The corrosion current density and corrosion potential were observed to vary with prestressing levels applied to the structural steel wire specimens. The structural steel wire prestressed to 80% of its original tensile strength and cathodically polarized at −1500 mV exhibited the highest current densities and lowest corrosion potentials after potentiodynamic polarization, which indicate that the above prestressing and cathodic polarization conditions lower the corrosion resistance of the material. Moreover, the tensile results show that the structural steel wire prestressed to higher levels and cathodically polarized at lower potentials was more susceptible to degradation of the tensile properties. The structural steel wire prestressed to 80% level and cathodically polarized at a potential of −1500 mV exhibits the lowest UTS and ductility. The tensile fracture surfaces of the steel wires prestressed and cathodically polarized under above conditions exhibit mostly quasi-cleavage brittle fracture character. Furthermore, the brittle regions were observed to increase with increasing the prestressing levels and decreasing the cathodic polarization potentials applied to the structural steel wires.

1. Introduction

Prestressing steel wires is employed in civil engineering for the prestressed concrete structures. The prestressing of the steel wires compensates the inadequate tensile strength as well as prevents cracking of the concrete structure. The prestressed concrete structures have smaller deformation and can absorb more tension than those of non-prestressed concrete structure. Cathodic protection is applied to the prestressed concrete structure to protect the steel wires from corrosion. Corrosion of the prestressed steel wires leads to damage of the concrete

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structure. The damage of the concrete structure may be due to the hydrogen embrittlement of pre-stressing steel and bond strength between concrete and prestressing steel. It is well recognized that hydrogen is evolved on the surface of steel during cathodic protection at more negative potential [1]. The steel is protected against corrosion due to the formation of passive iron oxide film on the steel surface resulted from active polarization. The effect of cathodic polarization is depended on the applied stress level and the size of corrosion induced cracking [2]. The durability of the concrete structure is affected by unsuitable post-tension of the concrete components such as prestressing steel wires. The failure of the prestressed concrete structure is attributed to the corrosion induced cracking. It has been shown that the hydrogen embrittlement may occur in partially prestressed elements [3] and the fractures of prestressing steel are due to hydrogen-induced cracking or anodic stress corrosion [4]. It has been concluded that hydrogen may enter the tendons as a result of cathodic protection or the acidification of the solution within corroding pits [5]. The susceptibility of highest-strength steel to hydrogen embrittlement was confirmed by slow strain-rate tests using pre-cracked, specimens under various environment conditions [6]. The susceptibility of prestressing steels to hydrogen embrittlement can be determined by the ammonium thiocyanate test [7]. It is found that the high-strength steel fails because its notched-bar tensile strength in the region of corrosion pits has been exceeded and the failure type in this case is brittle [8]. The prestressing steel wire is produced from hot rolled steel, which has pearlitic microstructure. The hot rolled steel is subjected to cold deformation to increases the tensile strength of the steel wire. The pearlite bands prevent diffusion of hydrogen through the surface of the stress free steel [9]. However, the tensile stresses increase hydrogen ingress into the steel leading to drastic decrease of the local grain boundary resistance and progressive failure of the steel [10].

The current research investigates the effect of prestressing and cathodic polarization on the corrosion behaviors and tensile properties of the structural steel wire. The corrosion resistance of the structural steel wire was evaluated by potentiodynamic polarization tests and slow strain tensile testing was conducted to determine the tensile properties and fracture modes under the above prestressing and cathodic polarization conditions.

2. Experimental procedure

Structural steel wire of 5 mm diameter was used in the current investigation. The chemical composition of steel wire is listed in Table 1. The tensile specimens were machined from the steel wire with a dimension of 200 mm. The tensile steel wire specimens were heated to 200 °C in an electric resistance furnace for 30 min to remove the residual stresses generated from machining and then prestressed to 20%, 40%, 60% and 80% of its ultimate tensile strength. The tensile steel wire specimens were pickled in nitric acid to remove the oxidized layer.

Table 1 – Chemical composition of prestressing steel wire (wt%).

C	Mn	Si	Cu	P	S
0.83	0.69	0.21	0.27	0.011	0.0033

Gamry PC4 potentiostat was used to conduct potentiodynamic polarization tests. The tests were performed in a corrosive solution of deaerated 3.5 M NaCl solution with pH 6.1, at a temperature of 25 °C. Argon deaeration of the solution was performed for 24 h before the potentiodynamic polarization tests. The steel wire specimens were immersed in corrosive solution for 20 min before starting of the measurements to reach a stable open circuit potential. Then the steel wire specimens were potentiodynamically polarized and scanned from the cathodic potential to the anodic potential at a scan rate of 0.2 mV/s. The electrochemical cell contains steel wire specimen as working electrode, platinum as counter electrode and saturated calomel as reference electrode (SCE).

Slow strain tensile test (SSRT) at strain rate of $10^{-6}\,s^{-1}$ in a solution containing $Ca(OH)_2$ with NaCl was conducted on the prestressed steel wire specimens. The steel wire specimens were cathodically polarized at −500, −1000, −1250 and −1500 mV in the electrochemical cell of stainless steel mesh as counter electrode and saturated calomel electrode (SCE) as reference. The fracture surfaces were studied under scanning electron microscope (SEM) to determine the fracture modes of the prestressed and cathodically polarized steel wire specimens.

3. Results and discussion

3.1. *Polarization behaviors of the prestressing structural steel wires*

Active anodic dissolution and Tafel behaviors were observed during potentiodynamic polarization of prestressing structural steel wires to various levels. However the active anodic dissolution was found to vary with the level of prestressing applied to the steel wire. This indicates that the prestressing procedure has a pronounced effect on the corrosion of the structural steel wires. Thus, the potentiodynamic polarization shows that the prestressing procedure enhances the active anodic dissolution of the structural steel wires as can be observed from Fig. 1. The corrosion potentials and

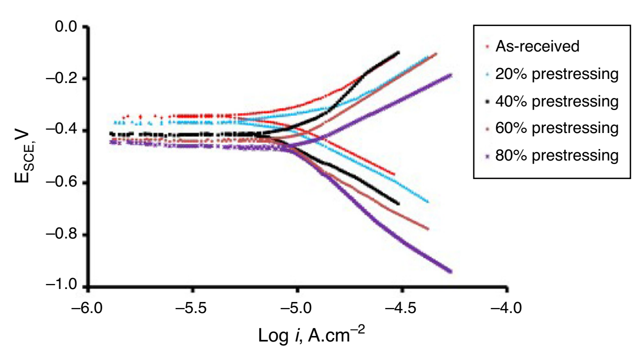

Fig. 1 – Potentiodynamic polarization curves of the as-received and prestressed structural steel wire specimens to various levels.

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