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SUSCEPTIBILITY OF PRESTRESSING STEEL WIRES TO HYDROGEN ASSISTED CRACKING IN A MODEL WORKING MEDIUM

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ABSTRACT

Susceptibility to hydrogen assisted cracking of cold drawn pearlitic steel wires used as a concrete reinforcement is studied in an alkali environment modelling pore liquid in concrete. Prestressing steel is established to become susceptible to hydrogen embrittlement under potentials –1.1V (SCE). The maximum fracture load as well as elongation to fracture decrease with cathodic potential increment, the effect is more notable under slow strain rate. Fracture mechanism in aggressive medium differs from it in air. The role of surface defects in the environmental assisted cracking is disscussed.

KEY WORDS. *Prestressing steel, reinforced concrete, hydrogenation, surface defects.*

INTRODUCTION

Intensive corrosion of reinforced concrete (RC) structures such as bridges and car park decks during its long term service can be attributed to the prolonged exposure of these structures to a chloride-contaminated environment, i.e. marine structures or through the application of de-icing salts. Although concrete carbonation also leads to reinforcement corrosion because of reducing of its alkalinity, presence of chlorides is the most important factor which deternines corrosion resistance of reinforcenent [1]. These ions penetrate the concrete cover and eventually reach the reinforcement where corrosion starts once a critical cloride threshold is exceeded. Corrosion results in thinning of steel wires and simultaneous expansion of corrosion products which leads to spelling of concrete cover. Due to electrochemical nature of reinforcement corrosion in concrete, the most effective methods of rehabilitation are also electrochemical, namely, cathodic protection, cathodic prevention or electrochemical chloride extraction. Additionally, the alkalinity of carbonated concrete can be restored using re-alkalisation. Most of RC structures contain prestressed elements such as slabs or beams and the application of electrochemical rehabilitation techniques to these elements would lead to savings through the extension of its service life. On the other hand, prestressed concrete contains high strength steel reinforcement which is suggested to be susceptible to hydrogen embrittlement, therefore a possible risk of hydrogen indused stress corrosion cracking could not be neglected.

Earlier investigations of prestressing pearlitic steel using both preckracked and notched specimens proved its high susceptibility to hydrogen assisted cracking [2–4]. The essential role of residual stresses and a concentrator's shape was established, and the hydrogen diffusion model including the effects of both hydrogen concentration and hydrostatic stress distribution was proposed to explain environmental and hydrogenation effects on pearlitic steel [2].

Fracture of smooth prestressing wires is studied insufficiently comparing to notched and pre-cracked ones. Among the researches concerning as-received wires, it is difficult to distinguish some clear regularities, but these data are of interest because the wires are put in concrete just in such state.

Parkins et al. [4] presented the investigations of the prestressing pearlitic steel carried out in the wide range of potentials, pH and under different strain rates. Strain rate of about 5×10^{-7} s^{-1} produced evidence, in the form of the reduction in area and maximum load, of environment sensitive fracture. Hovewer the trends were not invariably systematic with respect to the different exposure conditions and the maximum loads achieved in all of the tests were very similar, and again showed no strictly systematic variation.

One of the most widely used methods for essesment of hydrogen effect on steel reinforcement is the FIP Test Method (UNE 36-464-86) however it also leads to a broad experimental scatter. Presence of surface defects and the residual stresses may affect the results [5].

The aim of the research is to clarify the trends in hydrogen assisted fracture of prestressing steel wires and the role of surface defects in the process.

MATERIALS AND METHODS

Commercial pearlitic steel used in experiments was supplied in the form of cold drawn wires which had passed through seven cold drawing steps to attain the final diameter of 5.04 mm. Its chemical composition is following (wt. %): 0.88 C, 0.69 Mn, 0.22 Si, 0.010 P, 0.024 S, 0.239 Cr, 0.076 Ni, 0.010 Mo, 0.129 Cu, 0.118 V, Fe is balance. Plastic strain accumulated by steel due to the cold drawing process $\varepsilon^{P}_{accum} = 2ln(D_0 / D_i)$ is equal to 1.57. Hydrogen embrittlement of the prestressing steel was investigated by slow strain rate testing (10^{-6} – 10^{-7} s^{-1}) using smooth steel wires in as-received state. Surface of the tested wires was not grinded but only degreased by acetone and washed with water to bring them closer to the real working conditions. Specimens were tested on the MTS Alliance RT/100 testing mashine with softwere TESTWORKS 4. The initial distance between grips was 220 mm. Corrosive environment containing 1 g/l $Ca(OH)_2$ and 0.1 g/l NaCl (pH 12.5) reproduced alkaline working medium (pore liquid) in concrete [4, 6]. An electrochemical cell of 8 mm height was fixed around a specimen. The standard three-electrode scheme was used to upply cathodic polarization to the testes wires, in the range of –1.1… –1.4 V (SCE) and the potentiostat AMEL VOLTALAB PGP 201. At least three specimens were tested for each experiment.

RESULTS AND DISCUSSION

It is obvious from the load-displacement curves that the prestressing steel is susceptible to hydrogen embrittlement under cathodic polarization (Fig. 1). Essential changes in steel's mechanical behaviour have been detected under potential –1.1 V and lower. Hydrogenation does not influence on yield strength (all the curves overlap each other) while ultimate tensile strength is not reached due to hydrogen action.

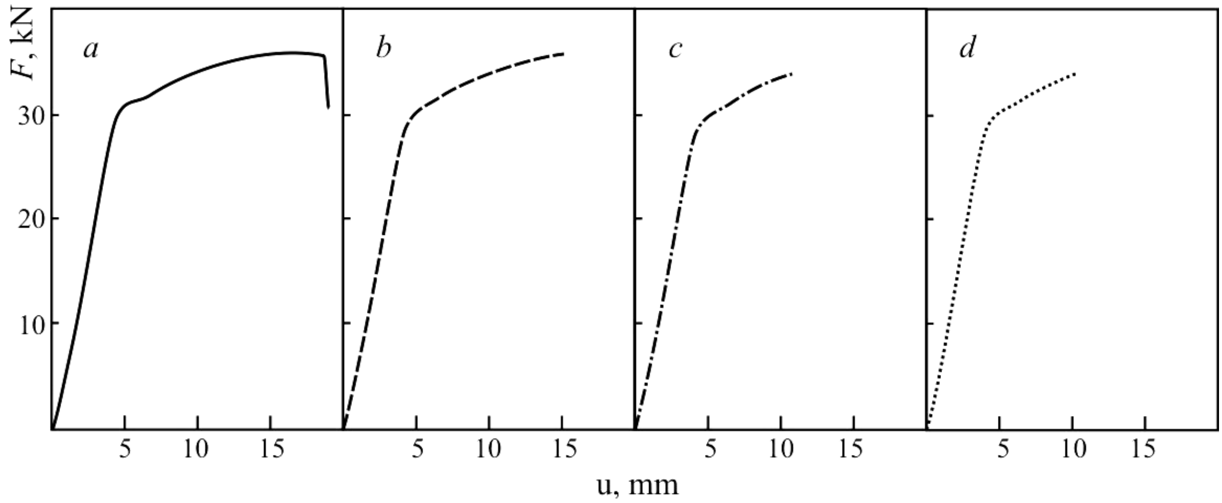

Fig. 1. Load-displacement curves of the prestressing steel in the medium containing 1 g/l $Ca(OH)_2$ + 0.1 g/l NaCl (pH 12.5) in air (*a*) and under cathodic polarization: –1.1 V (*b*), –1.2 V (*c*), –1.4 V (*d*); strain rate $7{,}5\times10^{-7}$ s^{-1}.

The effect of cathodic polarization on the mechanical characteristics, namely, elongation and fracture load of pearlitic cold drawn steels is shown in Fig. 2. For the both parameters this effect is more pronounced under lower strain rate because in this case hydrogen has more time to affect a metal. Under high strain rate, effect of hydrogen on such type of steels is negligible even under polarization of –1.5 V [4]. It is established also that resistance of high strength pearlitic steels to hydrogen assisted cracking is higher than martensite ones of the same strength [7]. Comperatively low (as for a high strength steel) hydrogen prospensity of cold drawn pearlitic wires can be explained by several factors: 1) specific microstructure with little grains and diminutive distances between ferrite and cementite lamellae; 2) low hydrogen diffusion coefficient ~10^{-12} cm/s; 3) compressive stresses at the wires surface produced by cold drawing process which suppress hydrogen uptake.

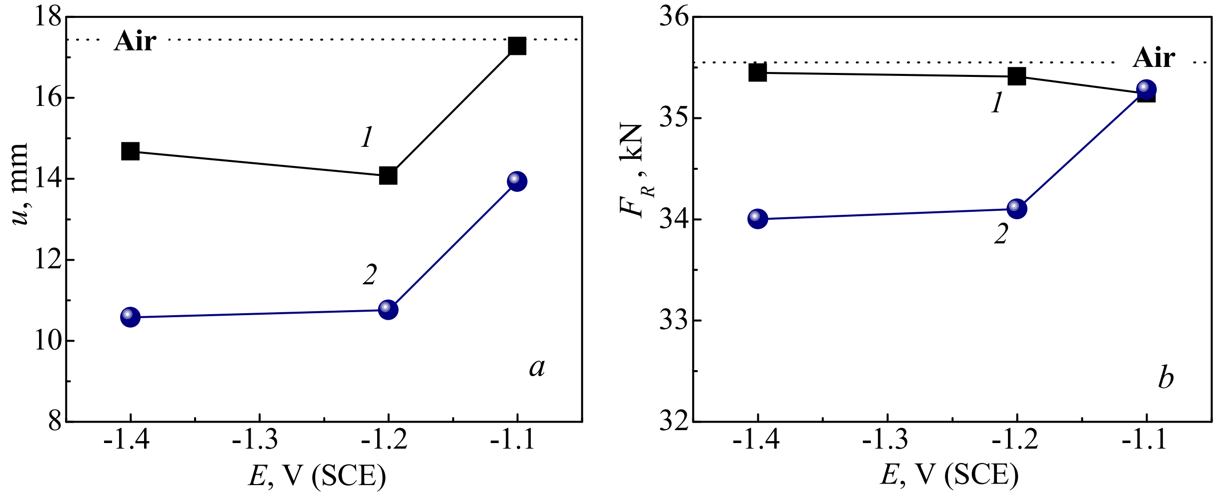

Fig. 2. Change in elongation to fracture u (a) and maximum load to fracture F_R (b) of the prestressing steel in SSRT test under cathodic polarization under different strain rates: *1* – 7.5×10^{-6} s^{-1}; *2* – 7.5×10^{-7} s^{-1}.

In the testing of the wires in as-received state, surface defects become very important since they are stress concentrators and the primary sites of hydrogen uptake [8]. There are two main types of surface defects: 1) defects produced by cold drawing process itself or due to transformation of those presented in a row material (hot rolled bar), *left*; 2) voids created in the sites of nonmetallic inclusions near the surface, *right*.

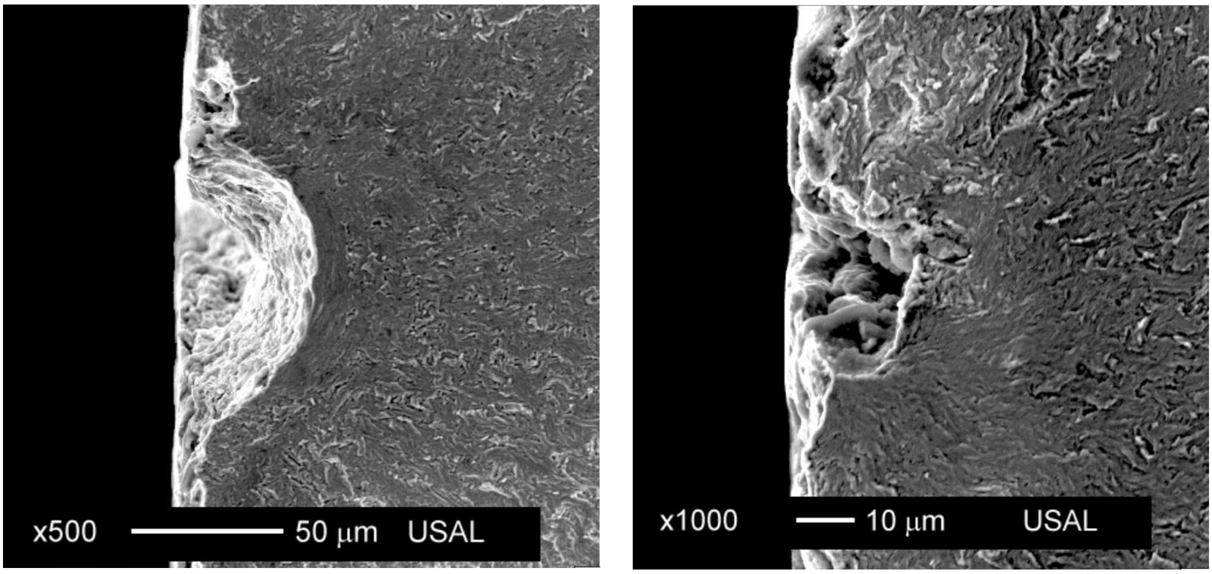

Fig. 3. Types of surface defects on the prestressing pearlitic steel.

It is shown that the defects of type 2 usually have hemispherical shape with a depth of about 25 µm [8]. These defects can form as a result of cold drawing or due to transformation of those created previously in the hot rolled steel. Evidently, fracture in aggressive medium begins from one of these defects (Fig. 4), in contrast to the fracture in air.

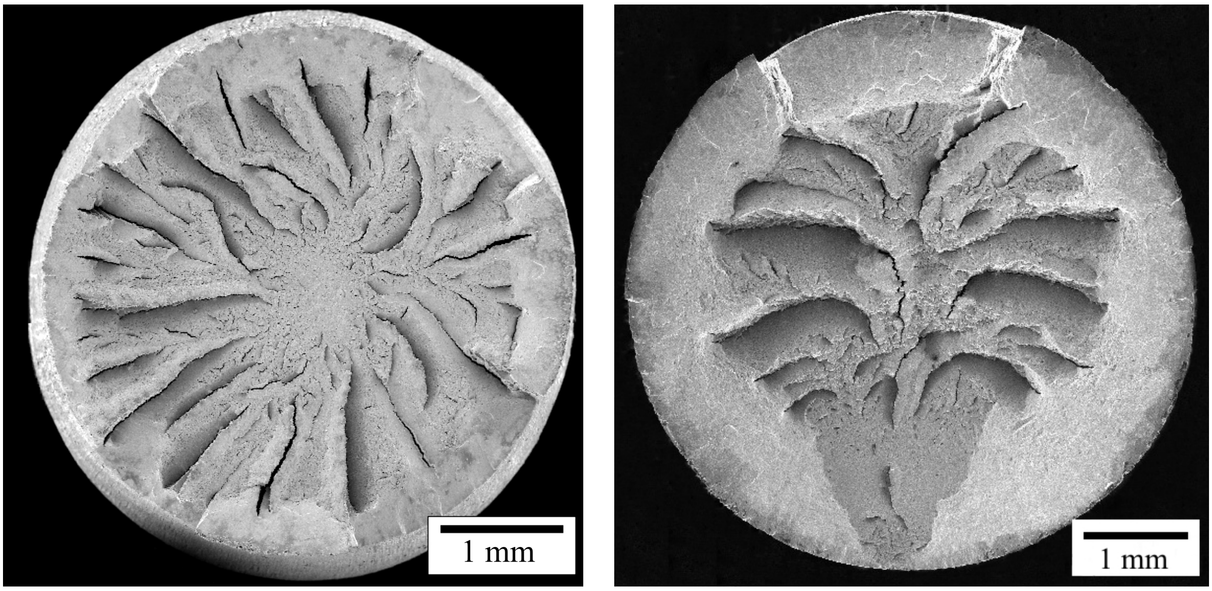

Fig. 4. Fracture maps of the prestressing pearlitic steel after the test in air (*left*) and in alkali medium (pH 12.5) under cathodic polarization –1.2 V (SCE) and strain rate 7.5×10^{-7} s^{-1} (*right*).

It is important to note that a shape of all tensile curves (both in air and environment) overlap which allows suggestion that some crack origins begin to appear in the centre of wires cross-section where residual tensile stresses already existed (produced by cold drawing) leading to cup-and-cone like fracture. The main crack grows from the surface towards the centre where it joins other crack nuclei and then spreads to the edge. Obviously, multiple initiation of cracks in initially plain specimens contributes to the process, and the tendency exists for the fracture path to follow longitudinal routes between transverse cracks when the latter did not lie in essentially the same transverse plane [4]. However more investigations, primarily fractographic, are required to clarify the fracture mechanism in smooth wires made of cold drawn pearlitic steel and the role of surface defects in it.

CONCLUSIONS

Cold drawn pearlitic steel is susceptible to hydrogen assisted cracking under potentials –1.1 V (SCE) and more, but this effect reveals only under low (10^{-6}–10^{-7} cm/s) strain rate.

In contrast to the test in air, fracture of the steel wires in the argessive medium begins at their surface which indicates the special significance of surface defects in the fracture process.

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