THE INFLUENCE OF POLARIZATION OF STEEL ON ITS MECHANICAL PROPERTIES

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Abstract

Full Text

PHYSICAL CHEMISTRY

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THE INFLUENCE OF POLARIZATION OF STEEL ON ITS MECHANICAL PROPERTIES

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We carried out experiments to determine the influence of polarization of steel on its mechanical properties in various electrolytes. A special attachment on a standard IM-12 tensile testing machine made it possible to rupture steel specimens in an electrolyte under their anodic or cathodic polarization by an external current source and to determine the mechanical characteristics of the steel during its polarization.

In order to be able to observe the effect of reduced plasticity, our experiments were conducted with soft annealed steel-3 of pearlite-ferrite structure. Specimens of this steel, 10 mm in diameter and with a gauge length of 100 mm, were washed before testing with aviation gasoline and desorbed with activated carbon. In cathodic polarization of the steel, the anode used was the same soft steel-3, lead, copper, or graphite. Aqueous solutions of 26% sulfuric acid, 18% caustic soda, or 3% NaCl were used as the electrolyte. The current density during polarization was varied from 0 to $\pm 60\ A/dm^{2}$; near zero, in some cases, changes in current density were made at intervals of $0.005\ A/dm^{2}$.

Fig. 1. Tensile diagram of differently polarized annealed steel-3. *a*—in air, *b*—under anodic polarization $D_a = 10$ A/dm^2, *v*—under cathodic polarization $D_k = 10$ A/dm^2. Electrolyte—acidic, anode and cathode Fe.

Tensile tests were carried out at a constant rate of extension $V = 2$ mm/min; the current was switched on simultaneously with putting the tensile machine into operation. The electrolyte was poured in immediately before the start of the experiment. The entire experiment lasted 10–15 minutes. The purpose of the experiment was to determine the ultimate strength σ , the yield point σ, the true stress at rupture σ (all in kg/mm^2), the relative elongation δ_{10}, and the relative reduction of area ψ of the steel at rupture (in percent) during its polarization, each point being determined as the average of three experiments.

Soft annealed steel-3, when stretched in air, gave a clearly expressed yield

Figure 2

Figure 2: Figure 2

plateau, considerable elongation and transverse reduction of area (Fig. 1, *a*), as well as the appearance of yield figures. The same was observed when specimens were stretched at the same rate in the electrolyte without polarization from an external current source, and also in the electrolyte under anodic polarization of the stretched specimen; in this case the specimens became covered with a thin film of oxides, and the plasticity of the steel changed only slightly.

lasted (Fig. 1, b). For all cases, the ratio of the concentrated deformation $\Delta l''$ to the total Δl was $\sim$ 25-30%.

Completely different results were observed in the tension of cathodically polarized specimens. These specimens fractured in a brittle manner, and fracture occurred mainly along the planes of maximum shear stresses (along the yield figures). Under cathodic polarization of the specimens, the plasticity indices δ_{10} and ψ, and the true stress at fracture σ_{true}, decreased especially strongly; the ultimate strength and yield strength did not change. The ratio of concentrated deformation to total deformation dropped sharply and amounted to only 9-12% (Fig. 1, c).

Fig. 2. Dependence of the relative elongation δ_{10} of annealed steel-3 on the magnitude and sign of polarization. The electrolyte is acidic; the anode and cathode are Fe. Point *A*—values of δ_{10} in air

Figure 2 gives the curve of the change in relative elongation δ_{10} of annealed steel-3 as a function of the sign of polarization and current density, with iron serving as the anode under cathodic polarization and as the cathode under anodic polarization; the electrolyte was acidic. Similar curves were obtained for the relative reduction of area and the true stress at fracture.*

As is seen from the diagram (Fig. 2), anodic polarization (at high current densities) does not affect the mechanical properties of steel. At low current densities of anodic polarization, a certain decrease in plasticity and true stress at fracture is observed in comparison with the data obtained in air (point *A*). Tests in the electrolyte without applying current from an external source, i.e., under conditions of ordinary electrochemical corrosion, when microcathodic and microanodic regions appear on the steel specimen, gave a decrease in plasticity (by 26%) and in true fracture stress, although fracture occurs with the presence of a neck, formed just as in air. When a cathodic potential is applied—even at the smallest current densities (0.005 A/dm^2)—the specimens fractured in a brittle manner along yield figures, and the maximum effect was observed at low current densities; it differed somewhat for different anode metals and different electrolytes (see Fig. 3). The effect of decreasing plasticity and true stress at fracture after the passage

Figure 3

Figure 3: Figure 3

Fig. 3. Dependence of the relative elongation δ_{10} of annealed steel-3 on the magnitude of cathodic polarization. *a*—electrolyte 3% NaCl, anode—steel; *b*—18% NaOH, anode—copper; *v*—26% H_2SO_4, anode—steel; *g*—26% H_2SO_4, anode—graphite; *d*—26% H_2SO_4, anode—copper; *e*—26% H_2SO_4, anode—lead

* The determination of the relative elongation δ_{10} could be carried out considerably more accurately than ψ and σ_{true}, because of the loss of the circular cross section of the fractured cathodically polarized specimen.

the maximum, with increasing cathodic current density, decreased monotonically (Fig. 3).

Table 1 gives the characteristics of the mechanical properties of steel-3 obtained in tests in air, in electrolyte without polarization of the specimen, and under cathodic polarization at the optimum value of the current density, when the greatest effect of change in the mechanical characteristics was observed. The characteristics of the mechanical properties of the steel are given both in absolute values and relative to the data of tests in air.

Table 1

Anode	Electrolyte	Current density	ψ Abs. %	ψ Rel. %	δ_{10} Abs. %	δ_{10} Rel. %	σ_{UTS} Abs. kg/mm^2	σ_{UTS} Rel. %	σ_{T} Abs. kg/mm^2	σ_{T} Rel. %	σ_{PC} Abs. kg/mm^2	σ_{PC} Rel. %
Fe	NaCl (3%)	O	69	98.5	32	100	80	92	28	100	39.5	98.7
Fe	NaCl (3%)	Opt	45	64.3	26	81	46	53.5	28.2	100.5	40	100
Cu	NaOH (18%)	O	68	97.2	31	97	75	86.3	28	100	40	100
Cu	NaOH (18%)	Opt	28	40.0	24	75	33	48.0	28	100	39	97.5
Cu	H_2SO_4 (26%)	O	48	68.6	28	87.6	48	55.2	29	103.5	40	100
Cu	H_2SO_4 (26%)	Opt	21	30.0	17	53.2	17	19.5	26.5	94.5	39	97.5
Pb	H_2SO_4 (26%)	O	46	65.7	27	84.5	53	61.0	28.5	101.7	40.5	101
Pb	H_2SO_4 (26%)	Opt	20	28.6	16	50	2	2.3	28.5	101.7	38.0	95
Fe	H_2SO_4 (26%)	O	42	60	27	84.5	41	47.2	28	100	39.5	98.7

Anode	Electrolyte	Current density	ψ Abs. %	ψ Rel. %	δ_{10} Abs. %	δ_{10} Rel. %	σ_{UTS} Abs. kg/mm^2	σ_{UTS} Rel. %	σ_{T} Abs. kg/mm^2	σ_{T} Rel. %	σ_{PC} Abs. kg/mm^2	σ_{PC} Rel. %
Fe	H_2SO_4 (26%)	Opt	25	35.7	18	56.3	15	17.3	27.5	98.2	37.5	93.8
C	H_2SO_4 (26%)	0	43	61.4	26.5	83	42	48.4	28.5	101.7	39.5	98.7
C	H_2SO_4 (26%)	Opt	26	37.2	17.5	54.7	25	28.7	28.5	101.7	37.5	93.8
			70	100%	32	100	87	100	28	100	40	100

The effect observed under cathodic polarization is explained by hydrogen charging, which causes embrittlement of the steel specimens being stretched. This hydrogen charging occurs at enormous speed and is concentrated along slip lines, i.e., in the zone of accumulation of vacancies and dislocations and of maximum concentration of deformation energy. As can be seen from the tensile curves (Fig. 1), hydrogen charging before the onset of plastic slips (i.e., before the yield point) does not occur because of the short duration of the experiment.

When specimens not polarized by an external current source are stretched in an acid electrolyte, when microcathodic and microanodic regions appear on the specimen being stretched, the decrease in plasticity is evidently also explained by embrittlement of the cathodic regions due to hydrogen. Under anodic polarization these cathodic regions are gradually suppressed, and at a certain value of current density the entire specimen becomes anodic, when hydrogen is no longer evolved on any of its regions. Weakening of the anodic regions of steel due to their corrosion damage in these cases evidently cannot occur because of the short duration of the experiment.

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Note: Figure translations are in progress. See original paper for figures.