Stress corrosion cracking of metals and alloys in aqueous environments is primarily an electrochemical phenomenon falling within the realm of the differential aeration hypothesis (DAH). As such, the local anode and the local cathode are spatially separated, with the former existing within the crack enclave (on the crack flanks and at the crack tip) and the latter existing on the bold, external surfaces that have greatest access to the cathodic depolarizer (e.g., O₂). The resulting current that flows from the local anode to the local cathode implies strong electrochemical coupling between the crack internal and external surfaces and this coupling, which has been experimentally probed in a variety of systems, including intergranular stress corrosion cracking, contains a great deal of information on events occurring at the crack tip. Furthermore, the crack length is predicted theoretically to exert a strong influence on crack growth rate, because, as the crack grows, a larger fraction of the potential drop between the crack tip and the external surface appears as IR potential drop down the crack and hence less potential drop is available to drive the cathodic reactions that consume the coupling current on the external surfaces. Consequently, the magnitude of the coupling current drops as the crack lengthens and hence so does the crack growth rate. The dependence of the crack growth rate on the electrochemical crack length has profound implications for the accumulation of SCC damage, including: (1) All cracks must eventually die (repassivate) when the potential drop available at the external surface becomes insufficient to maintain the separation between the local anode and local cathode. (2) The rate of accumulation of damage, as determined by the crack growth rate, decreases with time, such that a model that postulates a crack growth rate that is constant with time would significantly over-estimate the accumulated damage (crack length). The above relationships are illustrated with reference to intergranular stress corrosion cracking (IGSCC) in sensitized Type 304 SS in BWR primary coolant environment, IGSCC in sensitized Type 304 SS in thiosulfate solution at ambient temperature, and IGSCC in AISI 4340 steel in concentrated caustic at 70 °C. It is shown that, in all three cases, crack propagation is due to hydrogen-induced cracking. Finally, it is concluded that the crack growth rate is controlled by the kinetics of the cathodic reaction occurring on the external surface.
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