MODELING OF STRESS CORROSION CRACK INITIATIONS OF POLYETHYLENE PIPE TRANSPORTING CHLORINATED WATER

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Abstract
Stress corrosion cracking is one of the long-term failure mechanism of thermoplastic pipes when exposed to the oxidative agents, such as the chlorinated water. In this paper, the stress corrosion crack initiation model was suggested based on the diffusion of chlorinated water with oxidation, combining with the energy analysis by cracking. The multiple micro cracking, which is a dominant feature in stress corrosion cracking failure, was successfully simulated by the proposed model.

1. Introduction
Polyethylene (PE) pipe has been widely used in gas and water transportation piping systems because polyethylene is light, inexpensive as well as excellent mechanical properties. Although the PE is known to be chemically stable, long-term exposure to the oxidative agents generally causes a chemical degradation. In addition, the disinfectants such as chlorine dioxide leads accelerated oxidation in PE pipes, which are commonly used in water distribution networks. The deterioration of mechanical properties by oxidation under the mechanical loading such as internal pressure leads to the premature cracking of the pipe, which is known as the stress corrosion cracking (SCC) of polyethylene. It has been observed that the SCC of PE pipe is manifested in the simultaneous multiple microcrack initation on the inner surface of the pipe. Although the durability against the SCC is the major concern in water distribution pipes, the current test standards for PE pipes are time-consuming and expensive. The development of small-scale accelerated testing methods for PE materials, as well as the modeling of the SCC in pipe geometry, may be an effective way to address this problem. This paper deals with the development of a fundamental SCC initiation model to describe the multiple cracking behavior of PE pipe. The diffusion with oxidation concept was adopted for the mechano-chemical degradation kinetics of PE substances, and the multiple crack initiation was simulated by the energy analysis of the cracking. It was confirmed that the proposed model can predict both nominal brittle fracture with 1~2 crack initiation and SCC failure with multiple cracking, depending on the oxidative environments.

2. Results
Multiple SCC modeling was performed based on the mechano-chemical degradation concept of PE pipes transporting chlorinated water, under internal pressure. The detailed procedure is described below:

a. Diffusion of chlorinated water into the PE pipe wall is modeled with consideration of the diffusion sink due to the consumption by oxidative reaction. The chemical degradation on the inner surface of the pipe wall generates the degraded thin layer, as shown in Fig. 1a.
b. The oxidation-induced densification yields the additional hoop stress on the degraded thin layer (see Fig. 1a). The total hoop stress ($\sigma_{\theta\theta}$) results from the superposition of the effect of internal pressure and degradation-induced densification.
c. The reduction of specific fracture energy (SFE) of the degraded thin layer can be correlated with the oxidation-induced diffusion sink.
d. If we assume the number of crack initiation (N), the energy release rate (ERR) corresponding to the simultaneous cracking can be estimated, by using the weight function of multiple cracks. If the ERR increases up to its SFE, multiple crack initiation occurs through the degraded thin layer as shown in Fig. 1b.
e. For example, in the ERR and SFE comparison for N=1000, the intercept reveals the crack initiation time as indicated in the blue arrow (see Fig. 1c).

f. The *N* which has a shortest crack initiation time can be thought as actual crack initiation number, and the corresponding cracking time is then also simulated.

The pressurized PE pipe with outer radius of 55 mm and inner radius of 45 mm (SDR11) was considered in this study. The diffusion of chlorinated water into the radial direction was numerically solved, in consideration of consumption of diffused mass by irreversible chemical reaction. Through the energy analysis of ERR and SFE, the number of crack initiation with the shortest crack initiation time was estimated as shown in Fig. 1d. At the lower diffusion coefficient (*D*), the nominal brittle fracture with 1~2 crack initiation was obtained. However, if the *D* becomes high enough, the oxidative agent diffuses into the polymers quickly and the oxidative reaction can sufficiently occur. It induces chemically-driven brittle fracture with multiple crack initiation (see Fig. 1d).

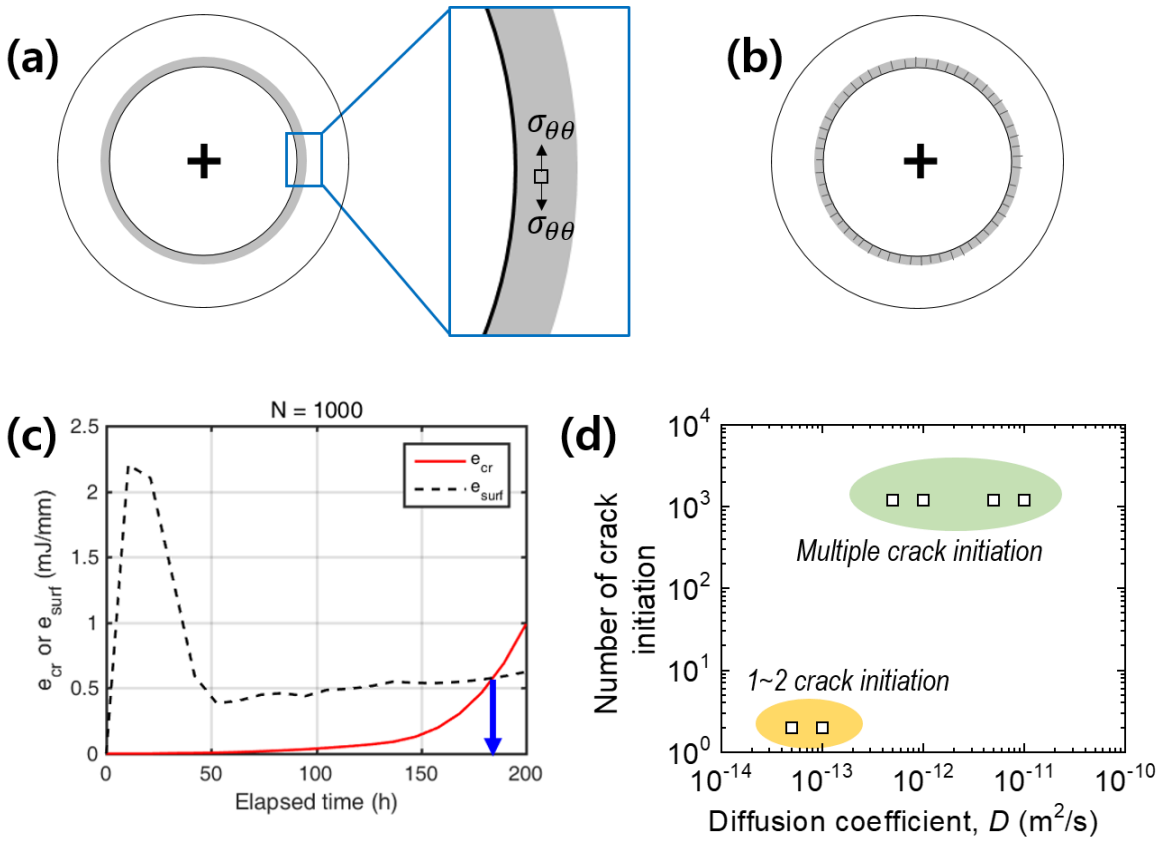

Fig.1 – Schematics of multiple SCC modeling: (a) Hoop stress build-up from the degraded layer, (b) multiple crack initiations in the degraded layer, (c) energy analysis between the ERR and SFE, and (d) number of crack initiation with change of diffusion coefficient.

3. Conclusions

This study fundamentally addresses the multiple SCC initiation behavior of PE pipes in the chlorinated environment. The diffusion model with sink was considered to simulate the formation of the degraded thin layer inside the pipe, and the number of crack initiation and cracking time could be estimated based on energy balance analysis. It was confirmed that the multiple SCC initiation behaviors could be successfully simulated by the proposed model.