Sensitivity Assessment of Fracture-Controlling Factors under High-Pressure Hydrogen

- Using the C-FaTH_2 Next-Generation Testing System and an Orthogonal Experimental Design -

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Hydrogen-based energy systems are expanding under global decarbonization policies, requiring polymeric materials used in seals, hoses, and liners to withstand repeated high-pressure hydrogen exposure. Dissolved hydrogen diffuses into polymers and, during depressurization, generates steep internal concentration and pressure gradients. This diffusion-controlled internal pressure build-up and subsequent supersaturation-induced cavity growth lead to blister formation and crack propagation, which may degrade sealing performance and increase leakage risk. Identifying dominant fracture-controlling factors under realistic multi-parameter conditions is therefore essential.

Experiments were conducted using the C-FaTH_2 (CERI Facility of Testing for High-pressure Hydrogen) next-generation system, which enables indoor handling of hydrogen up to 110 MPa and continuous unmanned operation for more than 24 hours. The system precisely controls pressurization and depressurization rates (0.5–300 MPa/min) and allows superimposed pressure pulsation, enabling reproducible simulation of complex pressure histories. Continuous operation is critical because damage evolution continues after depressurization as hydrogen diffusion proceeds under atmospheric conditions.

Two representative polymers were evaluated: LDPE (thermoplastic) and NBR (elastomer). Disk-shaped specimens (Φ18 mm × 2 mm) were exposed to cyclic high-pressure hydrogen. Seven control factors were considered (Fig. 1): pulsation, maximum pressure, high-pressure holding time, pressurization rate, low-pressure holding time, depressurization rate, temperature, and material type. An L18 orthogonal array reduced 4,374 possible combinations to 18 experimental conditions. Each condition consisted of 20 high-pressure hydrogen impulse cycles, with total test durations reaching approximately 120 hours in some cases.

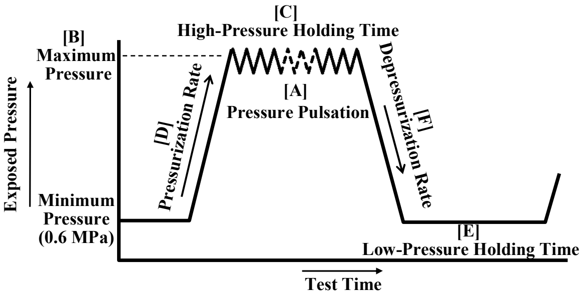

Fig1. Factors Associated with Blister and Crack Formation in Polymeric Materials under High-Pressure Hydrogen Exposure (Service Conditions)

Damage was quantified using an optical transmission method with a normalized MAP value (0.0–1.0). The main effects plot (Fig. 2) shows that maximum pressure, temperature, and depressurization rate are the dominant fracture-controlling factors. LDPE exhibits strong dependence on temperature and pressure, whereas NBR is most sensitive to depressurization rate. Pressure pulsation showed only minor influence within the tested range. These differences are attributed to variations in diffusion behavior and mechanical properties.

The combination of a 24-hour continuous testing platform and orthogonal experimental design enables systematic identification of fracture-controlling parameters under realistic multi-factor conditions, providing a quantitative basis for material selection and reliability improvement in high-pressure hydrogen systems.

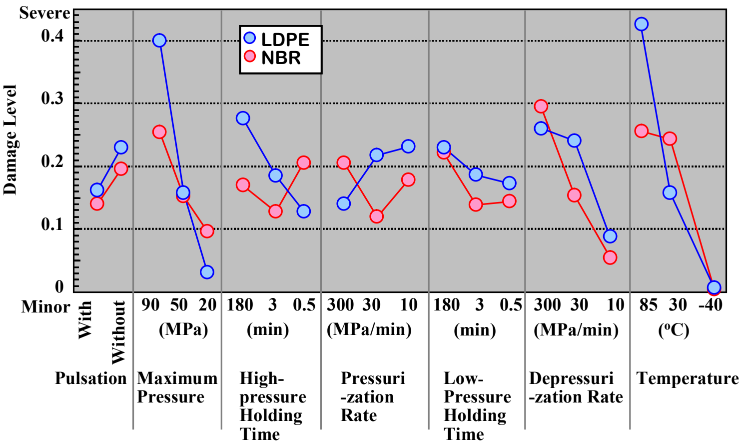

Fig. 2 Main Effects of Control Factors on Damage in LDPE and NBR

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