

Durability Prediction of Fuel Cell Adhesive Sheets Using an FC System Simulator

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The expansion of polymer electrolyte fuel cell (PEFC) technology into heavy-duty mobility (HDV) applications requires significantly improved durability because of longer operating hours and higher operating temperatures. In Toyota mass-produced FC cells, the adhesive sheet is used to provide sealing for hydrogen, air, and coolant as well as electrical insulation between the cathode and anode (Fig. 1). The core layer of the adhesive sheet consists of polyethylene naphthalate (PEN), which offers excellent mechanical properties and chemical resistance. However, PEN is known to undergo hydrolysis under severe temperature and humidity conditions, potentially resulting in durability degradation. Therefore, a durability prediction methodology is required to ensure reliable operation under various HDV driving conditions.

In this study, a durability prediction method was developed by integrating chemical degradation and mechanical fatigue concepts into an FC system simulator. The simulator calculates transient distributions of temperature, relative humidity, and gas pressure inside the fuel cell during HDV operation. PEN molecular weight degradation due to hydrolysis was modeled using material test results under different temperatures, pressures, and humidity conditions. Mechanical strength degradation was characterized from S-N tests using specimens with different molecular weights. Stress generated in the adhesive sheet was evaluated by finite element analysis and linked to operating conditions through response functions. Finally, cumulative fatigue damage was calculated using Miner's rule based on the time-varying cell environment predicted by the FC system simulator.

Fig. 2 summarizes the predicted durability behavior of PEN under HDV operation. The molecular weight continuously decreases with operating time because of hydrolysis. However, the reduction rate is moderated by the low humidity conditions that occur during high-load operation. The simulation results indicate that the required durability target of 30,000 h is achieved with negligible cumulative damage. Even at the challenging target of 50,000 h, the cumulative damage ratio remains approximately 8.5%, satisfying the durability criterion of less than 10%. Although the model predicts a rapid increase in damage beyond this period, the results demonstrate that the current adhesive-sheet design provides sufficient durability for the target HDV application.

The proposed methodology successfully combines hydrolysis-induced material degradation and fatigue damage accumulation within a FC system simulator. The approach is applicable not only to PEN hydrolysis but also to other degradation modes and operating scenarios. Furthermore, it can support both hardware design optimization and system control development, contributing to enhanced durability and reliability of future fuel cell systems.

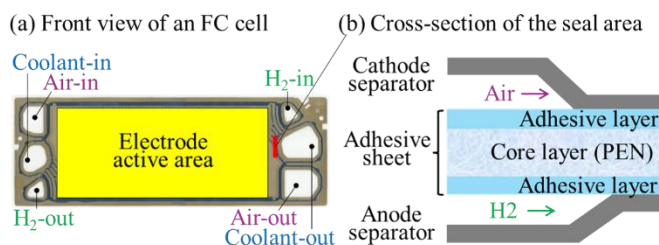


Fig.1 FC cell configuration

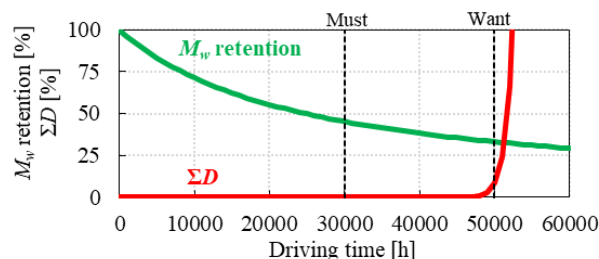


Fig.2 PEN durability analysis results for HDV driving