Mechanical Damage Propagation in Polymer Electrolyte Membrane Fuel Cells under Humidity and Temperature Cycles

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Significant advancements have been made in polymer electrolyte membrane fuel cell (PEMFC) technologies over the past decade in areas such as water management, thermal management and electrocatalysis. However, challenges still remain in the area of mechanical degradation [1]. Reported mechanical damage in PEMFCs includes cracks and delaminations (separation of the layers) in the membrane electrode assembly (MEA), pore size distribution changes in the porous layers, and fractures in the gas diffusion layer (GDL) [2–4]. Such mechanical damage can lead to fuel crossover, performance degradation, and reduced durability [5]. Therefore, it is necessary to identify and control the mechanisms that are involved in damage initiation and propagation in the PEMFC.

Mechanical stresses induced by temperature and relative humidity cycles during PEMFC operation play an important role in the initiation and evolution of mechanical damage in the MEA [6]. The PEMFC is particularly susceptible to damage in transportation applications, where the fuel cell is subjected to a high number of start-up/shut down cycles and hence a higher number of humidity and temperature variations compared with stationary applications [7].

To the authors' best knowledge, there is a scarcity in the number of studies regarding mechanical damage evolution in PEMFCs due to humidity and temperature variation [3,4]. Rong et al. [4] modeled a three-phase microstructure including Nafion, a carbon/platinum (C/Pt) agglomerate and a pore. They found that frequent start-up and shutdown cycles of fuel cells leads to earlier initiations of damage at the catalyst layer (CL)/membrane and GDL/CL interfaces. Poornesh et al. [3] investigated the effect of the CL material properties on the crack propagation in the MEA. These valuable studies have provided insight into the mechanical damage evolution in PEMFCs; however, the geometry of the modeled crack and the applied loading regime in their studies are idealized and do not represent the real critical situation in PEMFCs.

The goal of this work is to establish a comprehensive numerical model to study the delamination and crack evolution in PEMFCs. A finite element (FE) model based on the cohesive zone theory [8] is employed to describe the delamination propagation at the membrane/CL interface due to duty cycles. Furthermore, the effects of the alignment of the bipolar plates (alternating and aligned gas channels), frequency and the number of humidity and temperature cycles, and the initial length of the delmaination on the damage propagation pattern are investigated.

The employed FE model includes two bipolar plates, two GDLs, two CLs, a Nafion membrane, and a delamination, as shown in Figure 1. In order to simulate the loading condition in a working PEMFC, cycles of humidity and temperature are applied to the model as shown in Figure 2. The humidity increases from 30% to 95%, while the temperature increases from 20 ^{0}C to 86 ^{0}C[6].

This work provides insight into the importance of considering mechanical damage to the MEA under working conditions in transportation applications.

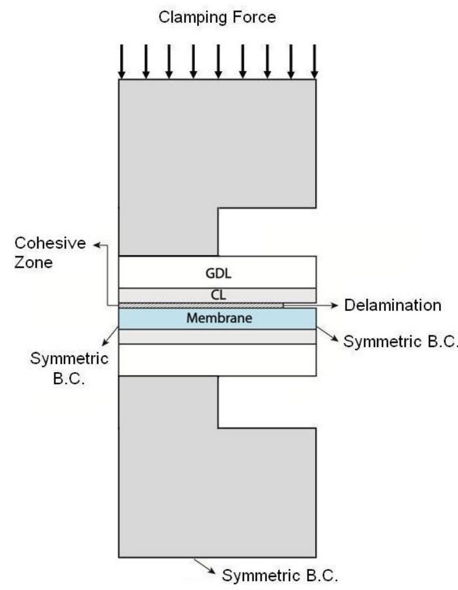

Figure 1. Schematic of the computational domain (aligned gas channels).

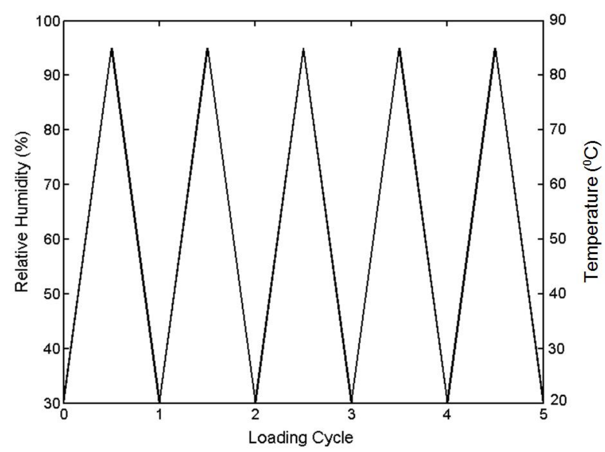

Figure 2. Temperature and humidity cycles applied to the membrane [6]

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