IN-SITU EXPERIMENTAL INVESTIGATION OF FATIGUE CRACK PROPAGATION MECHANISMS IN POLYMER ELECTROLYTE MEMBRANE OF FUEL CELL UNDER OVERLOADING EFFECT

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Abstract

The fatigue crack growth mechanisms in polymer electrolyte membranes of fuel cell are investigated under single overload conditions. In-situ SEM testing and in-situ optical microscopy testing combined with digital image correlation technique are conducted. The results show that the residual stress dominates the fatigue crack growth after the application of small overload cycle leading to subsequent fatigue crack growth retardation while larger overload cycle causes crack tip sharpening, resulting in fatigue crack growth retardation reduction or even acceleration.

1. Introduction

The polymer electrolyte membrane fuel cells (PEMFCs), which convert the chemical energy in H_2 and O_2 gas into electric energy and produce water as a by-product, have reviewed increasing attention. The polymer electrolyte membrane (PEM) acted as the key part of PEMFC dominate the durability of PEMFC to some extent. The water generation and absorption due to hydration and dehydration process can result in expansion and contraction of the membrane during the fuel cell operation. This dimensional change will converts into cyclic mechanical loading to the membrane. So far, extensive studies have been done to probe the fatigue crack propagation behavoir under constant amplitude loading (CAL). There is still lack of experimental studies concerning fatigue crack propagation behavior and its underlying mechanisms in PEM under overloading effect.

2. Results

The perfluorosulfonic acid ionomer membrane, i.e. Nafion 212 manufactured by Dupont, were tested in as-received state. The fatigue crack growth rate (FCGR) obtained from the specimens that are subjected to the CAL with stress ratio of 0.3 inserted by a single spike OL are plotted against their corresponding effective J integral range (ΔJ_{eff}) in Fig. 1. It is seen from Fig. 1(a) that overload-induced retardation degree increases as the OL ratio (R_{ol}) rises from 1.2 to 1.5. However, the retardation extent is reduced when the OL ratio reaches to 1.6, indicated as the green square in Fig. 1(b), and FCGR can be even accelerated when the OL ratio gets to 1.7, denoted as the purple inverted triangle in Fig. 1(b).

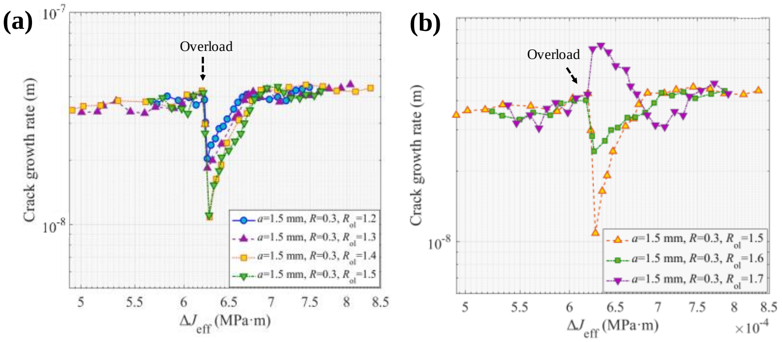

Fig.1. FCGR variation under single OL: (a) R_{ol} ranges from 1.2 to1.5 and (b) R_{ol} ranges from 1.5 to 1.7.

The fracture surfaces of the specimens respectively obtained under the single OL condition with small overload cycle (R_{ol}=1.3) and large OL ratio (R_{ol}=1.7), are given in Fig. 2(a) and 2(b). Region a in each figure indicates the crack increment of the OL cycle. It can be found that narrow spacing fatigue striations still appears after the applied small OL cycle while large spacing of fatigue striation can be clearly detected after large OL. The crack tip profile before OL, right after the large OL cycle and right after the small OL cycle are respectively shown in Fig. 2(c)-(e). It is observed that the crack tip is sharpened after the large OL cycle while it is still blunted after the small OL cycle. This reveals that the large OL cycle can sharpen the crack tip and thus reduce the impediment of fatigue crack propagation.

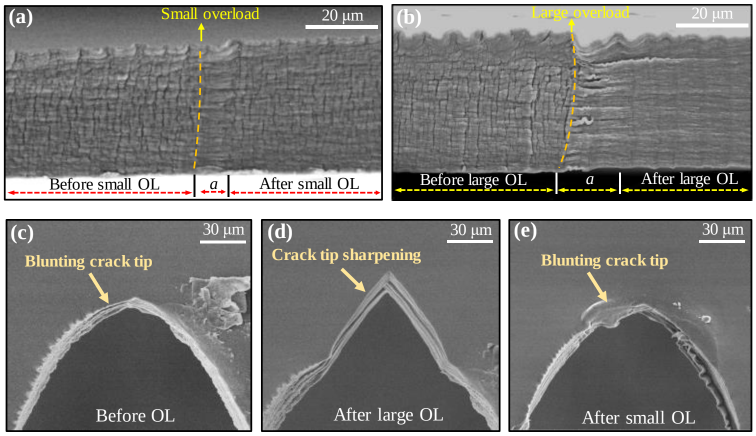

Fig.2 Fracture surface under single OL condition with (a) small OL cycle and (b) large OL cycle. Micrographs of crack tip (c) before OL; (d) right after large OL; (e) right after small OL.

The near-tip strain distribution at maximum loading before OL, right after the large OL cycle and right after the small OL cycle are respectively exhbited in Fig. 3(a)-(c). By comparing the strain concentration level before OL, it is found that the crack tip strain concentration level declines after the application of small OL. In this case, the enlarged compressive residual stress left by previous overload cycle will govern the subsequent fatigue crack growth, leading to the crack growth retardation. However, the strain concentration level increases after the applied large OL,which is a result of overload-induced crack tip sharpening, as indicated in Fig. 2(d).

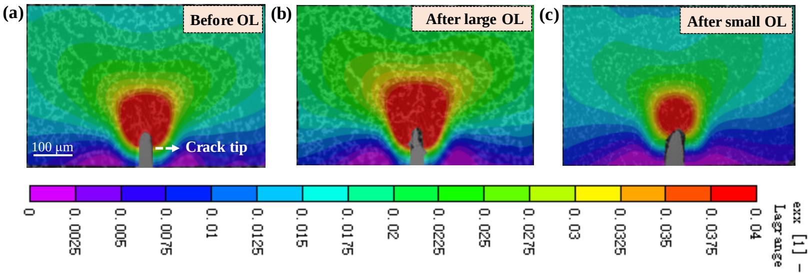

Fig.3 The near tip strain distribution: (a) before OL; (b) after large OL; (c) after small OL.

3. Conclusions

The small OL cycle with can retard the fatigue crack propagation in Nafion 212 membrane since the compressive residual stress plays a dominant role in post-overload crack propagation. The large OL cycle can diminish this retardation or even accelerate the fatigue crack propagation due to the large OL induced crack tip sharpening. The enhancement of stress concentration at the sharpened crack tip will compromise overload-induced compressive residual stress at crack front, leading to the reduction of retardation extent, or even resulting in crack growth acceleration when it exceeds the compressive residual stress.

Acknowledgements

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