Investigation of Degradation in Functionalized h-BN/PBI Composite Membranes for HT-PEMFCs

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High-temperature proton exchange membrane fuel cells (HT-PEMFCs) require membranes that maintain proton conductivity, acid retention, dimensional integrity, and chemical stability under hot, low-humidity, and oxidative operating environments [1].

Phosphoric-acid-doped polybenzimidazole (PBI) membranes remain among the most widely investigated HT-PEMFC electrolytes because of their high thermal stability, strong acid–base interaction with H_3PO_4, and suitability for anhydrous proton transport at elevated temperatures, as discussed in comprehensive studies by Li et al. and Escorihuela et al. [1,2]

However, long-term durability is still limited by oxidative degradation, acid leaching, and mechanical weakening, especially when radical species such as •OH and HOO• attack vulnerable sites in the PBI backbone during fuel-cell operation or accelerated Fenton testing [3].

Inorganic filler incorporation has been widely explored to mitigate these limitations by enhancing acid retention, polymer–filler interactions, and membrane resistance against chemical and morphological deterioration. Among these fillers, hexagonal boron nitride (h-BN) is particularly attractive because of its high thermal and chemical stability, electrically insulating character, and layered structure. Hussin, Budak, and Devrim reported PBI/boron nitride composite membranes for HT-PEMFC applications, showing that BN incorporation can improve membrane performance and stability when well dispersed in the PBI matrix [4,5].

Our recently published work on functionalized BN-based PBI composite membranes, including pyridine-PBI/boron nitride systems, demonstrated improved proton conductivity, acid retention, and oxidative resistance through stronger acid–base and hydrogen-bonding interactions among the PBI matrix, phosphoric acid, and functional groups on BN. [5].

In this study, the Fenton-test-induced degradation behavior of functionalized h-BN/PBI composite membranes was investigated for HT-PEMFC applications. After oxidative exposure, the membranes were characterized using FTIR to identify changes in chemical bonding and functional groups, XRD to evaluate changes in amorphous/crystalline structure and h-BN-related diffraction features, and SEM to examine surface morphology, filler dispersion, and degradation-induced defects. Since h-BN-based fillers have been reported to improve the thermal and chemical robustness of PBI composite membranes, this multi-analytical investigation provides insight into how functionalized h-BN contributes to the oxidative durability and structural stability of PBI-based composite membranes for HT-PEMFC operation.

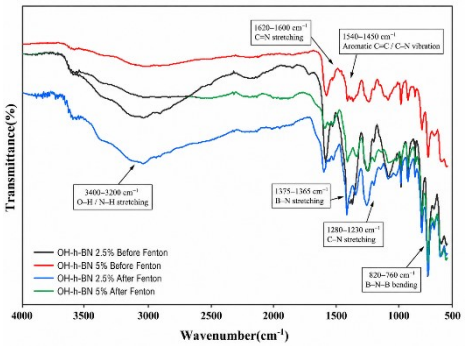


Figure 1. FTIR spectra of P-PBI/OH-h-BN membranes before and after Fenton test.

The FTIR spectra of P-PBI/OH-h-BN composite membranes before and after 8 days of Fenton exposure show the main functional groups of both the P-PBI matrix and OH-functionalized h-BN filler. The broad band at 3400-3200 cm^{-1} corresponds to O-H/N-H stretching, which becomes more pronounced after Fenton treatment, indicating stronger hydrogen bonding and possible oxidation-induced hydroxylated groups. The bands at 1620-1600 cm^{-1} and 1540-1450 cm^{-1} are assigned to C=N stretching of the benzimidazole ring and aromatic C=C/C-N vibrations, respectively [6]. Their changes after Fenton exposure suggest partial oxidative attack on the benzimidazole/aromatic structure. The 1280-1230 cm^{-1} region, related to C-N stretching, also changes after oxidation. The h-BN-related bands at 1375-1365 cm^{-1} and 820-760 cm^{-1}, assigned to B-N stretching and B-N-B bending, remain observable, confirming the stability and reinforcing role of the inorganic filler [5,6].

References

[1] S. Subianto, Polym. Int. 63 (2014) 1134–1144. https://doi.org/10.1002/pi.4708
[2] J. Escorihuela, Ó. Sahuquillo, A. García-Bernabé, E. Giménez, V. Compañ, Nanomaterials 8 (2018) 775. https://doi.org/10.3390/nano8100775
[3] J.H. Liao, Q.F. Li, H.C. Rudbeck, J.O. Jensen, A. Chromik, N.J. Bjerrum, J. Kerres, W. Xing, Fuel Cells 11 (2011) 745–755. https://doi.org/10.1002/fuce.201000146
[4] D.E. Hussin, Y. Budak, Y. Devrim, Int. J. Energy Res. 46 (2022) 4174–4186. https://doi.org/10.1002/er.7418
[5] A.H. Ali, Z. Pekdemir, E. Erünal, R.G. Akay, Int. J. Hydrogen Energy 210 (2026) 153588. https://doi.org/10.1016/j.ijhydene.2026.153588
[6] M.R. Berber, Front. Energy Res. 8 (2020) 571651. https://doi.org/10.3389/fenrg.2020.571651



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