

Supplementary data

Unveiling the long-term degradation mechanisms of the sealing structures for durable PEM fuel cells by ex-situ accelerated stability evaluation of a membrane electrode assembly

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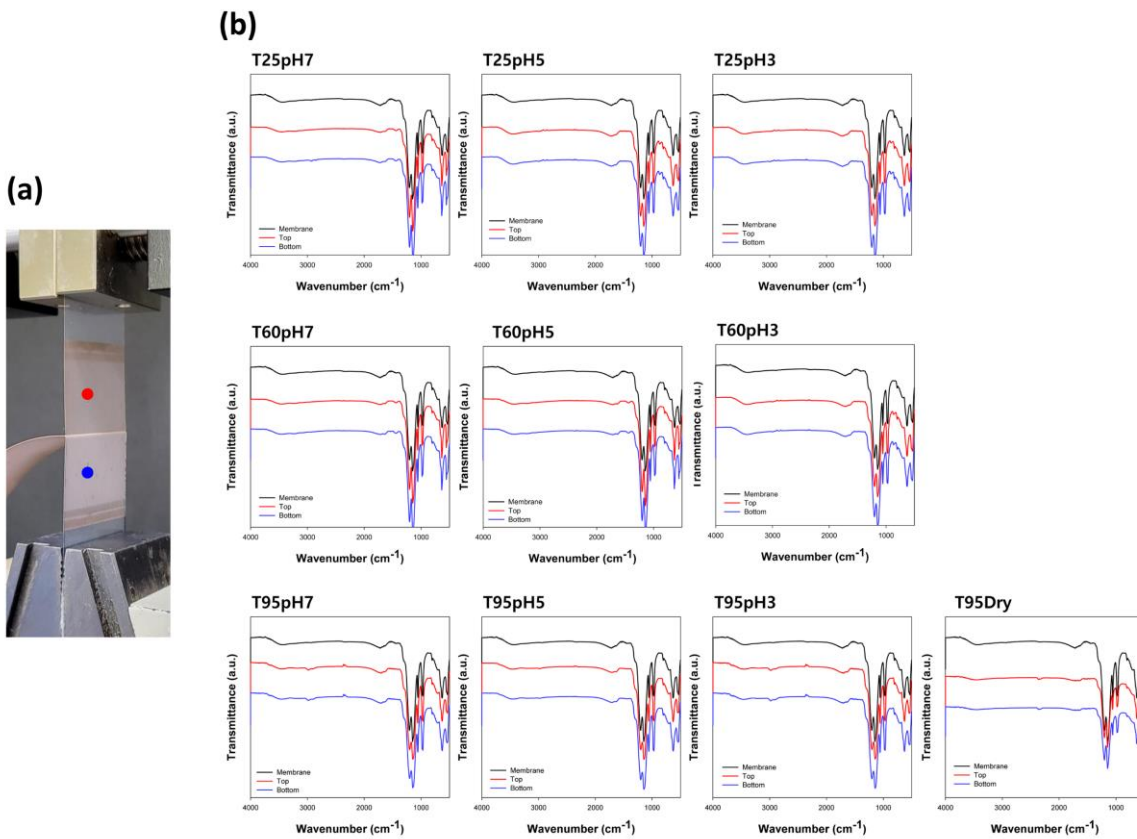


Fig. S1. (a) Photographic image of 180° T-peel test. (b) FT-IR Spectra of the upper and lower surfaces of the peeled MEA frame films according to the different acceleration environments.

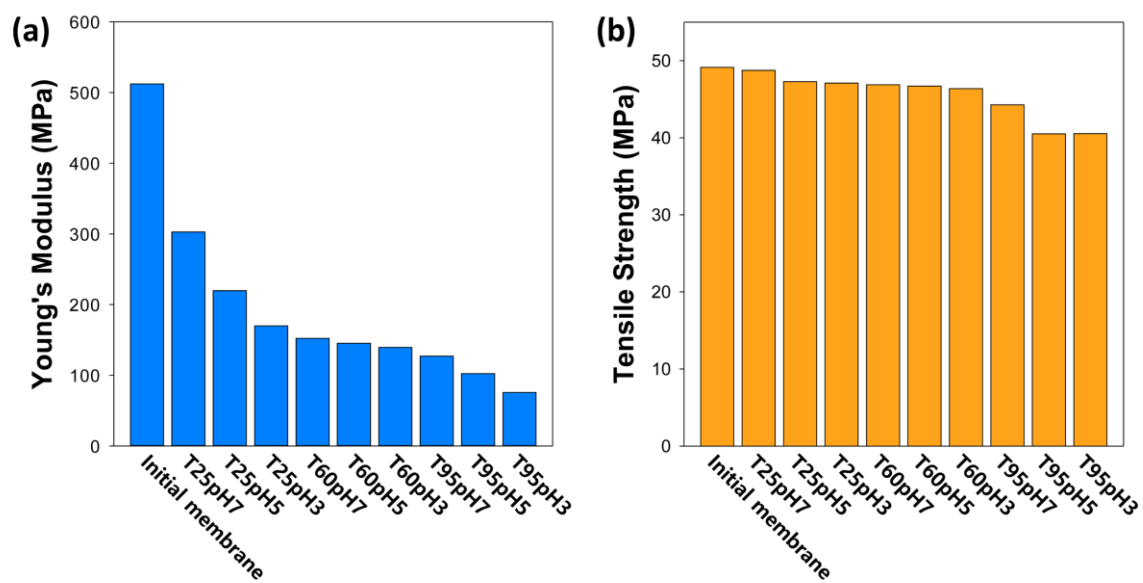


Fig. S2. (a) Young's modulus and (b) tensile strength of the Nafion membrane films after accelerated evaluation for 504 h under two-factor, three-level conditions.

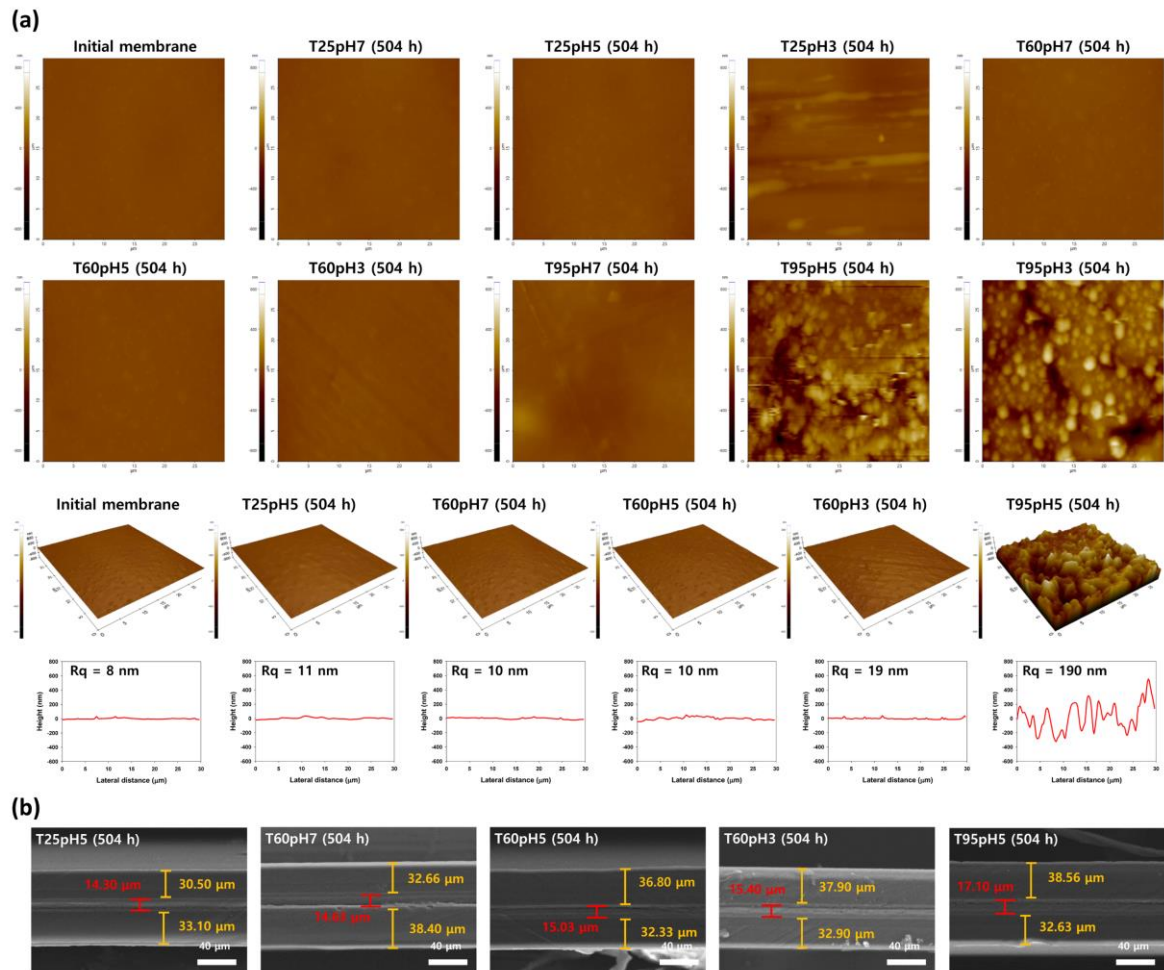


Fig. S3. (a) AFM images of membrane surfaces and (b) cross-sectional FE-SEM images of the MEA frame films after accelerated evaluation for 504 h under two-factor, three-level conditions.

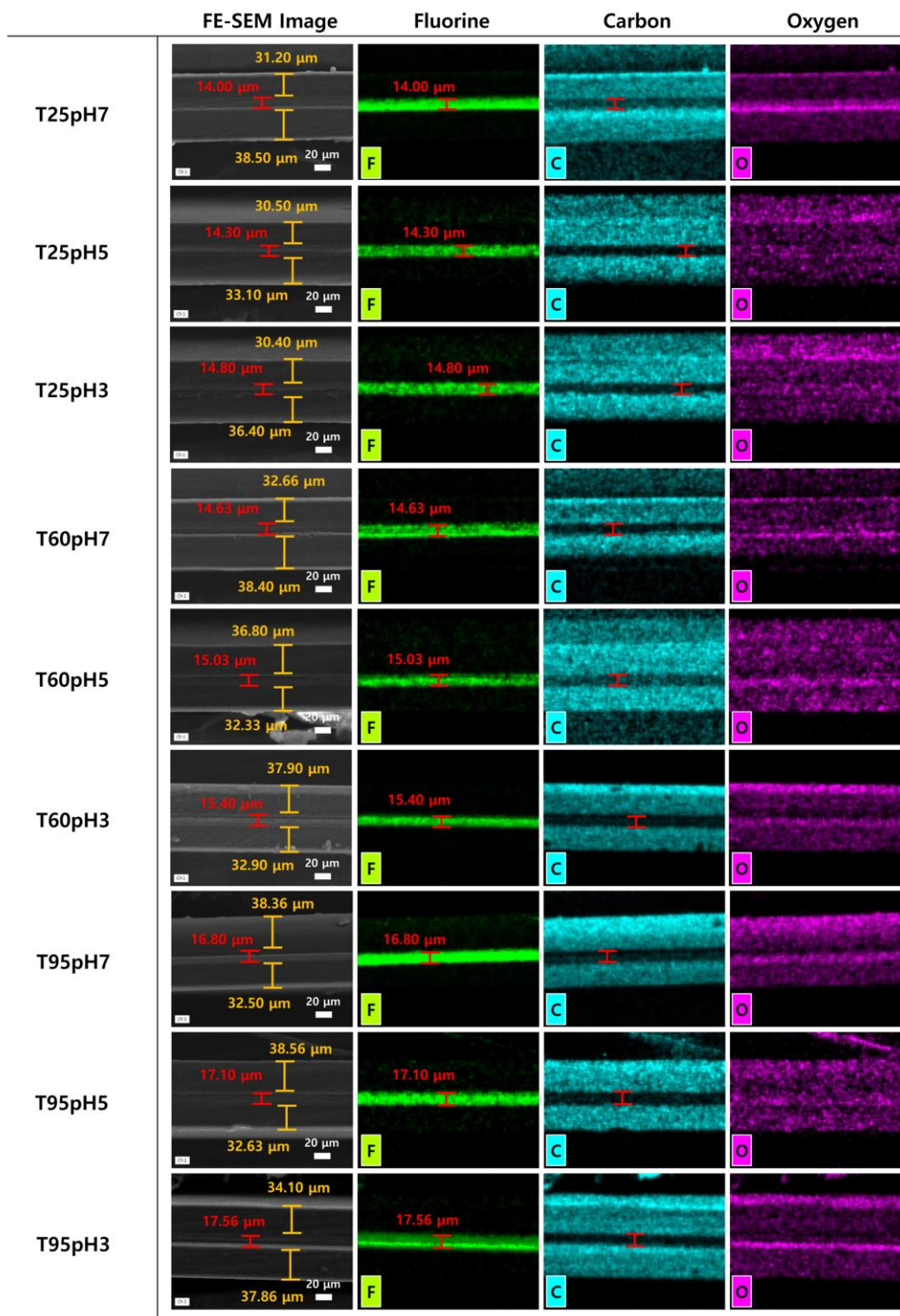


Fig. S4. Cross-sectional FE-SEM and EDS images of the MEA frame films after accelerated evaluation for 504 h under two-factor, three-level conditions.

Table S1. Peel strengths of the MEA frame films after two-factor, three-level experiment

Sample	Peel Strength (N/mm)					
	Initial (0 h)	1 h	3 h	6 h	12 h	18 h
		24 h	72 h	168 h	336 h	504 h
T25pH7	0.22 (± 0.010)	0.22 (± 0.012)	0.23 (± 0.009)	0.22 (± 0.007)	0.25 (± 0.011)	0.23 (± 0.007)
		0.22 (± 0.010)	0.20 (± 0.030)	0.21 (± 0.01)	0.19 (± 0.01)	0.18 (± 0.004)
T25pH5	0.21 (± 0.010)	0.22 (± 0.013)	0.22 (± 0.004)	0.20 (± 0.012)	0.21 (± 0.006)	0.21 (± 0.011)
		0.20 (± 0.010)	0.20 (± 0.020)	0.19 (± 0.010)	0.17 (± 0.005)	0.19 (± 0.010)
T25pH3	0.20 (± 0.007)	0.26 (± 0.005)	0.19 (± 0.006)	0.18 (± 0.011)	0.19 (± 0.020)	0.19 (± 0.005)
		0.20 (± 0.009)	0.18 (± 0.007)	0.18 (± 0.010)	0.17 (± 0.005)	0.16 (± 0.009)
T60pH7	0.21 (± 0.010)	0.26 (± 0.009)	0.20 (± 0.019)	0.22 (± 0.013)	0.20 (± 0.006)	0.19 (± 0.005)
		0.20 (± 0.010)	0.17 (± 0.010)	0.14 (± 0.010)	0.13 (± 0.020)	0.12 (± 0.020)
T60pH5	0.24 (± 0.002)	0.24 (± 0.018)	0.21 (± 0.001)	0.17 (± 0.016)	0.18 (± 0.007)	0.17 (± 0.006)
		0.14 (± 0.009)	0.13 (± 0.006)	0.13 (± 0.014)	0.12 (± 0.005)	0.12 (± 0.003)
T60pH3	0.26 (± 0.016)	0.19 (± 0.007)	0.18 (± 0.008)	0.18 (± 0.009)	0.18 (± 0.010)	0.17 (± 0.010)
		0.13 (± 0.006)	0.13 (± 0.003)	0.12 (± 0.010)	0.12 (± 0.014)	0.12 (± 0.002)
T95pH7	0.27 (± 0.030)	0.20 (± 0.026)	0.21 (± 0.023)	0.19 (± 0.011)	0.16 (± 0.013)	0.14 (± 0.014)
		0.11 (± 0.010)	0.09 (± 0.022)	0.11 (± 0.021)	0.07 (± 0.007)	0.09 (± 0.01)
T95pH5	0.24 (± 0.005)	0.17 (± 0.036)	0.16 (± 0.011)	0.16 (± 0.024)	0.13 (± 0.019)	0.12 (± 0.043)
		0.10 (± 0.001)	0.08 (± 0.001)	0.09 (± 0.005)	0.06 (± 0.003)	0.05 (± 0.010)
T95pH3	0.27 (± 0.040)	0.19 (± 0.020)	0.15 (± 0.015)	0.14 (± 0.039)	0.13 (± 0.020)	0.12 (± 0.022)
		0.11 (± 0.006)	0.08 (± 0.005)	0.11 (± 0.011)	0.05 (± 0.010)	0.05 (± 0.002)
T95Dry	0.25 (± 0.012)	-	-	-	-	-
		0.30 (± 0.012)	0.33 (± 0.020)	0.32 (± 0.014)	0.34 (± 0.035)	0.35 (± 0.011)

Table S2. Water uptakes of the MEA frame films under two-factor, three-level conditions

Sample	Initial weight (g)	After 30 min (g)	Water uptake 30 min (%)	After 60 min (g)	Water uptake 60 min (%)
T25pH7	0.1722	0.1760	+ 2.40 (± 0.17)	0.1802	+ 4.42 (± 0.21)
	0.1677	0.1721		0.1752	
	0.1695	0.1735		0.1765	
T25pH5	0.1723	0.1776	+ 3.31 (± 0.26)	0.1802	+ 4.43 (± 0.18)
	0.1725	0.1780		0.1797	
	0.1717	0.1780		0.1795	
T25pH3	0.1749	0.1820	+ 4.25 (± 0.14)	0.1810	+ 4.88 (± 1.00)
	0.1678	0.1750		0.1775	
	0.1770	0.1848		0.1865	
T60pH7	0.1698	0.1770	+ 4.87 (± 0.48)	0.1808	+ 6.46 (± 0.89)
	0.1699	0.1791		0.1827	
	0.1697	0.1781		0.1788	
T60pH5	0.1655	0.1791	+ 6.50 (± 1.40)	0.1794	+ 7.34 (± 0.75)
	0.1651	0.1730		0.1765	
	0.1754	0.1868		0.1872	
T60pH3	0.1719	0.1843	+ 6.96 (± 0.96)	0.1873	+ 7.20 (± 1.46)
	0.1750	0.1890		0.1877	
	0.1708	0.1805		0.1800	
T95pH7	0.1726	0.1828	+ 5.58 (± 0.33)	0.1891	+ 9.15 (± 0.32)
	0.1737	0.1826		0.1895	
	0.1731	0.1830		0.1883	
T95pH5	0.1681	0.1824	+ 8.05 (± 0.52)	0.1854	+ 9.62 (± 0.84)
	0.1678	0.1801		0.1848	
	0.1672	0.1811		0.1813	
T95pH3	0.1695	0.1861	+ 8.11 (± 1.37)	0.1835	+ 9.60 (± 1.33)
	0.1664	0.1799		0.1854	
	0.1711	0.1821		0.1867	

Table S3. Young's modulus and tensile strength of the membrane films after two-factor, three-level experiment

Sample	504 h	
	Young's Modulus (MPa)	Tensile Strength (MPa)
Initial membrane	512.27 (\pm 16.25)	49.13 (\pm 0.83)
T25pH7	302.86 (\pm 33.23)	48.74 (\pm 1.25)
T25pH5	219.71 (\pm 14.02)	47.28 (\pm 1.51)
T25pH3	169.91 (\pm 16.27)	47.08 (\pm 1.83)
T60pH7	152.26 (\pm 15.99)	46.87 (\pm 1.93)
T60pH5	145.28 (\pm 15.34)	46.70 (\pm 3.43)
T60pH3	139.45 (\pm 15.22)	46.37 (\pm 0.82)
T95pH7	127.12 (\pm 14.02)	44.27 (\pm 1.70)
T95pH5	103.12 (\pm 20.19)	40.50 (\pm 0.30)
T95pH3	75.77 (\pm 29.04)	40.53 (\pm 2.14)