

Characterization

The intrinsic viscosity (η) of PEF and PEFDn was measured at 25°C using a Ubbelohde viscometer with 0.5 g/dL solutions in phenol/1,1,2,2-tetrachloroethane (50/50 wt.%). Molecular weights and distributions were determined by gel permeation chromatography (GPC) using an Agilent PL-GPC 220 system at 40 ° C, with chloroform as eluent (1 mL/min flow rate) and sample concentration of 1.0 mg/mL. ¹H NMR spectra were recorded at 298 K on a Bruker AVANCE NEO 600 spectrometer with *d*-TFA as solvent.

Morphologies were examined using scanning electron microscopy (SEM, Verios G4 UC, Thermo Scientific, USA) on gold-sputtered samples. For atomic force microscopy (AFM, Veeco, USA), specimens were prepared by dissolving the polymer in HFIP, spin-coating onto pre-cleaned silicon wafers, and evaporating the solvent. The graphitization degree of char residues was analyzed by micro-Raman spectroscopy (Renishaw inVia Reflex) via ID/IG ratio evaluation

Vertical burning (UL-94) test was conducted with a 5400 vertical burning tester (Suzhou Yangyi Vouch Testing Technology Co., Ltd.) from ASTM D3801 using 100 mm × 13 mm × 3.2 mm sample. Following ASTM D2863-97, LOI was determined using a 5801 digital oxygen index analyzer (Suzhou YangYi Vouch Testing Technology Co. Ltd) with 100 mm×6.5 mm×3.2 mm specimens. Combustion behavior of PEF and PEFDn was investigated using a Cone Calorimeter 6810 (Suzhou YangYi Vouch Testing Technology Co. Ltd) according to GB/T 16172:2007 at 35 kW/m², with samples sized 100 mm×100 mm×3.2 mm.

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Mechanical properties were measured according to ASTM D638 on a

Zwick/Roell Z1.0 universal tester (Germany) at a crosshead speed of 10 mm/min using dumbbell-shaped specimens (35 mm × 2 mm × 1 mm, n = 5). Unnotched Izod impact strength was determined on a GT-7045-HML tester with 10 mm × 4 mm × 80 mm specimens (n = 5). Oxygen permeability was measured at 23 °C and 50% relative humidity on a Labthink VAC-V2 system following GB/T 1038–2000, with films of 200 μm thickness and 9.7 cm diameter. Ultraviolet–visible (UV–vis) spectra were recorded using a Lambda 950 UV/Vis/NIR spectrophotometer with 200 μm-thick films.