Note S1. The calculation of antioxidant's density

The specific gravity bottle method is used to evaluate the antioxidant's density, and the following formula is used to determine the specimen's density at 23°C or 27°C:

$$\rho_s = \frac{m_s - \rho_{IL}}{m_1 - m_2} \#(S1)$$

Where in ρ_s is the density of the test, m_s is the apparent mass of the specimen, m_1 is the apparent mass of the liquid required to fill the empty specific gravity flask, m_2 is the apparent mass of the liquid required to fill the specific gravity flask in which the specimen has been dissolved, and ρ_{IL} is the density of the impregnating liquid (g/cm^3) at 23 °C or 27 °C as provided by the supplier or as calculated.

Note S2. The calculation of solubility parameters

The solubility parameters were calculated based on the Small[1] method and the group contribution method according to the following equation:

$$\delta_a = \frac{\rho_a \Sigma F_i}{M_0} \#(S2)$$

Where δ_a represents the solubility parameter, ρ_a represents the density, M_0 represents the molar mass of the compound or the mass of the polymer repeating unit, and ΣF_i represents the sum of the molar gravitational constants of all the groups of the polymer or compound weight, i.e., the sum of the contributions of all the groups to F.

Note S3. The calculation of crystallinity

Their crystallinity was determined by the enthalpy of melting after eliminating the thermal history. DSC samples were taken from impact test fracture surfaces. The relative crystallinity X_c was calculated as:

$$X_C = \frac{\Delta H_C}{\omega \Delta H_m^0} \#(S3)$$

Where ΔH_c is melting enthalpy (J/g);

ΔH_m^0 is melting enthalpy of PA6 with 100 % crystallization (230 J/g);

ω is the quality percentage of PA6 in the mixture.

Note S4. Mobility ratio (^{M_t}) of the antioxidants

The PA6 samples (9 mm × 4 mm × 4 mm) containing antioxidants were extracted in 20 mL ethanol at room temperature for different days. After extraction, the UV absorption spectrum of the solution was tested to determine the content of antioxidants in the ethanol. The standard curve of absorbance and concentration of two antioxidants in ethanol is shown in (Fig. S1). The mobility ratio (^{M_t}) of the antioxidants from the PA6 samples was calculated by the following equation:

$$M_t(\%) = \frac{m}{M} \times 100\% \#（S4）$$

Where m is the concentration of antioxidant in ethanol after extraction, mg/L, and M is the weight of the PA6 sample spiked with antioxidant, mg.

Note S5. Calculation of energy gap of PEA, PPA

The energy gap[2] (ΔE) is usually used to characterize the electron transfer capacity and thus evaluate the antioxidant capacity of antioxidants. The specific calculation formula is as follows:

$$\Delta E_{HOMO-LUMO} = E_{HOMO} - E_{LUMO} \#(S5)$$

E_{HOMO} is the highest occupied orbital, E_{LUMO} is the lowest unoccupied orbital, and $\Delta E_{HOMO-LUMO}$ is the energy range between the two.

Note S6. FTIR analysis

FTIR spectra were recorded on the surface of the spline by a Nicolet iS50 FTIR spectrophotometer (ThermoFisher Scientific, America) with an ATR unit. The measurements were carried out in a range of 4000-400 cm^{-1}. The spectral resolution was 4 cm^{-1} and the number of scans per spectrum was 32.

Note S7. Differential scanning calorimetry analysis (DSC)

In the DSC test, PA6, PA6/PEA, and PA6/PPA ware carried out on DSC 25 Instruments (TA Instruments, America) at a heating rate of 10 °C/min to 250 °C for two minutes. Then the cooling rate is 10°C/min to 40 °C for two minutes, and then the heating rate is 10°C/min to 250 °C for two minutes, and the final cooling rate is

10°C/min to 40°C ending. The whole process is carried out under nitrogen atmosphere. The degree of crystallinity of PA6, PA6/PEA, and PA6/PPA was conducted by the melting enthalpy after eliminating heat history. The whole process is carried out under nitrogen atmosphere.

Note S8. Thermal gravimetric analysis (TGA)

The thermal stability was tested under an N_2 atmosphere with 10 °C/min from room temperature to 600°C in a thermogravimetric analyzer (TGA55, TA Instruments, America).

Note S9. Morphology of impact fracture surface (SEM)

The morphology of the impact fracture surface sprayed with gold was observed using a scanning electron microscope (QUANTA25OFEG, FEI Company, America) equipped with an energy spectrometer. In SEM, the electron beam energy is 20 eV, spot 3.0, and the work distance is 20 mm.

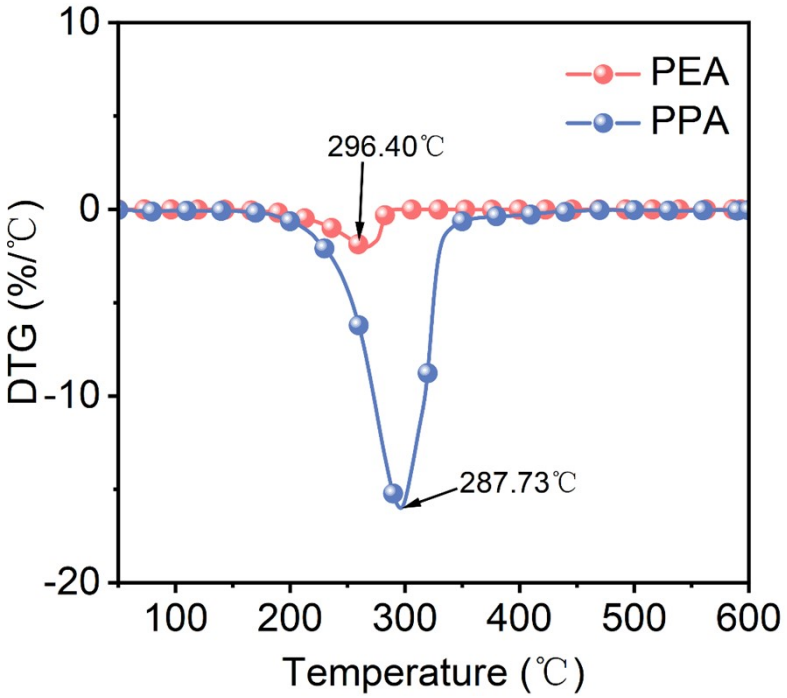


Figure S1. Maximum weight loss temperature for PEA and PPA

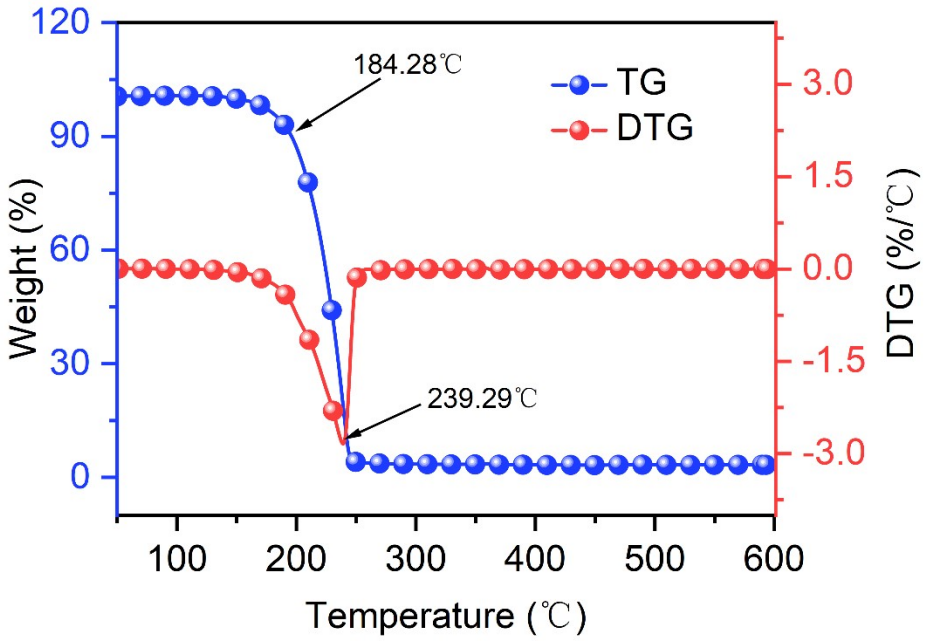


Figure S2. TG and DTG plots for AO

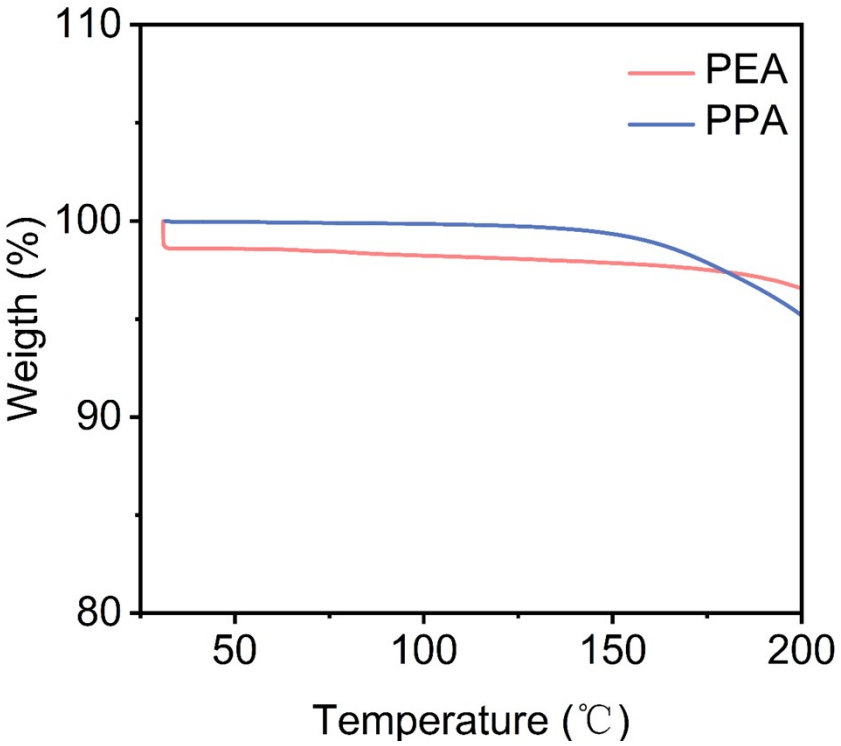


Figure S3. TG curves of PEA and PPA at 25-200℃

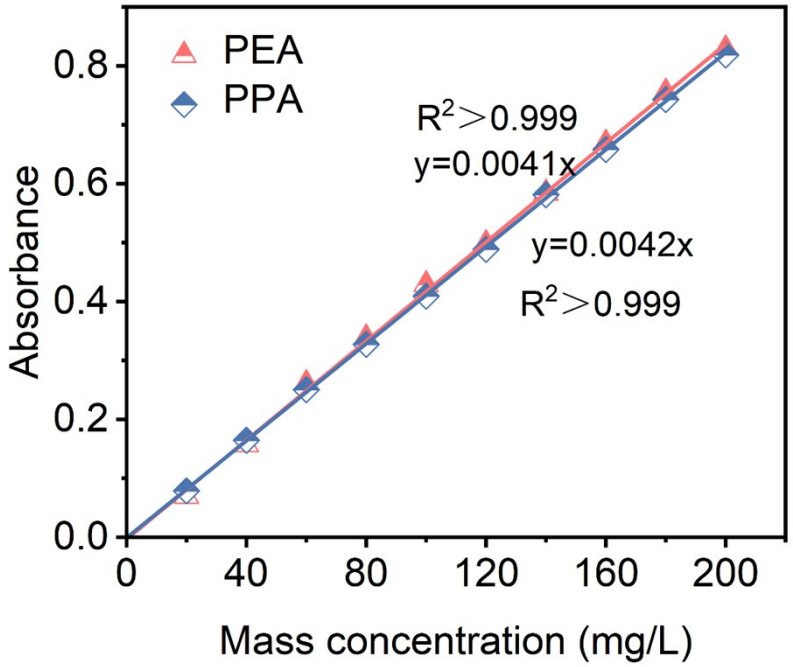


Figure S4. Standard curves for PEA and PPA

Table S1. AO and antioxidant thermogravimetric correspondence parameters

Sample	$T_{5\%}$ (℃)	T_{max} (℃)	WLR_{max} (%/℃)
AO	184.28	239.29	0.068
PEA	217.30	296.40	-0.610
PPA	201.28	287.73	0.030

Table S2. Absorbance of PPA corresponding to different reaction times

Reaction time	1min	40min	80min	180min	240min
Absorbance	1.0519	0.3893	0.2859	0.1945	0.1321

Table S3. DPPH scans under different concentrations of antioxidants (90 min)

n_{OH}/n_{DPPH}	0	0.25	0.5	0.75	1	1.25	1.5	2
PEA	0	58.28	73.25	80.92	84.61	86.60	88.49	91.66
PPA	0	63.38	75.11	82.67	85.74	88.16	89.64	92.44

n-level reaction rate equation

$$v_A = -\frac{dc_A}{dt} = k_A C_A^n = \frac{dx}{dt} = k_A(c_{A0} - x)^n \#(S5)$$

The reaction rate constant k_A is the dimension of concentration $^{(1-n)}$ * time^{-1}

known quantity	zero order reaction	first-order reaction	second-order reaction
calculate the general formula	$-\frac{dc_A}{dt} = k_A C_A^0 = k_A$	$-\frac{dc_A}{dt} = k_A C_A$	$\frac{1}{C_A} - \frac{1}{C_{A0}} = k_A t$
Initial concentration Final concentration	$C_{A0} - C_A = k_A t$	$\ln\frac{C_{A0}}{C_A} = k_A t$	$\frac{x}{(C_{A0} - x)C_{A0}} = k_A t$

Table S4. Kinetic fitting parameters for PEA and PPA

	reaction order					
	zero order reaction		first-order reaction		second-order reaction	
	K/mol·m^{-3}·s^{-1}	R^2	K/s^{-1}	R^2	K/(mol·m^{-3})$^{-1}$·s^{-1}	R^2
PEA	0.000220	0.777	0.00283	0.855	0.05919	0.938
	0.000197	0.758	0.00346	0.873	0.06956	0.948
	0.000236	0.805	0.00328	0.885	0.06252	0.952
PPA	0.000174	0.826	0.00276	0.942	0.08133	0.989
	0.000197	0.849	0.00255	0.972	0.07711	0.991
	0.000206	0.831	0.00319	0.941	0.1039	0.994

Table S5. Calculation of dissociation energy of antioxidants

Groups	Enthalpy (Hartree)	Revised value	DBE (Hartree)	BDE (KJ/mol)
H radicals	-0.494951	0.010654	0.117019	307.2333845
PEA radicals	-1232.582798	0.526055		
PEA	-1233.194768	0.539377		
PPA radicals	-1271.863533	0.555356	0.115005	301.9456275
PPA	-1272.473489	0.568609		

Table S6. Calculation of energy level difference of PEA, PPA

	E_{HOMO} (eV)	E_{LUMO} (eV)	$\Delta E_{HOMO-LUMO}$ (eV)
PEA	-5.64	-1.34	4.30
PPA	-5.68	-1.40	4.28

Table S7. Stress-strain data for PA6, PA6/PEA, PA6/PPA at yield point

Sample	$stress$ (%)	$strain$ (MPa)
PA6-0	13.96	68.14
PA6-1	14.93	75.69
PA6-2	-	-
PA6-4	-	-
PA6-8	-	-
PA6-12	-	-
PA6/PEA-0	13.35	70.51
PA6/PEA -1	15.2	80.84
PA6/PEA -2	14.37	81.41
PA6/PEA -4	14.87	81.58
PA6/PEA -8	12.21	77.68
PA6/PEA -12	-	-
PA6/PPA-0	12.65	69.63
PA6/PPA -1	15.46	81.21
PA6/PPA -2	14.64	80.77
PA6/PPA -4	15.15	80.89
PA6/PPA -8	13.37	81.07
PA6/PPA -12	-	-

Table S8. Calculation of samples by the impregnation method

	Ms (g)	m_1 (g)	m_2 (g)	ρ_{IL} (g/cm^3)	ρ_s (g/cm^3)
PEA	1.199	43.240	42.105	1	1.056
PPA	1.169	43.239	42.240	1	1.170

Table S9. Corresponding parameters required for solubility calculation by the group contribution method

Groups	Number (PEA)	Number (PPA)	Groups contributions to F(J/cm^3)$^{1/2}$	ΣF (J/cm^3)$^{1/2}$ (PEA)	ΣF (J/cm^3)$^{1/2}$ (PPA)
-CH_3	6	7	420	2520	2940
-CH_2-	5	4	280	1400	1120
-OH	1	1	754	754	754
-COO-	2	2	512	1024	1024
-CH-	1	2	57	57	114
Quanternary caobon	4	4	0	0	0
phenyl	1	1	1377	1377	1377

Table S10. Required parameters for solubility parameters of PEA and PPA

	ρ_a (g/cm^3)	m_0 (g/mol)	ΣF_i (J/cm^3)$^{1/2}$	δ (J/cm^3)$^{1/2}$	$\Delta\delta$ (J/cm^3)$^{1/2}$
PEA	1.056	390.24	7329	19.840	6.480
PPA	1.170	376.49	7132	22.167	4.153

PA6 solubility parameter is 26.32 (J/cm^3)$^{1/2}$

Table S11. PA6 and stabilized PA6 crystallographic analysis

sample	Aging Time (Day)	γ (%)	α (%)
PA6	0	88.88	11.12
	1	82.54	17.46
	2	83.58	16.42
	4	79.52	20.48
	8	78.45	21.55
	12	76.45	23.55
PA6/PEA	0	75.91	24.09
	1	76.65	23.34
	2	73.47	26.53

	4	74.95	25.05
	8	72.42	27.58
	12	71.82	28.18
PA6/PPA	0	72.13	27.87
	1	75.51	24.49
	2	66.48	33.52
	4	65.47	34.53
	8	62.63	37.37
	12	61.88	38.12

Table S12 PA6 and stabilized PA6 melt crystallization parameters

	Sample			
	Aging days	T_{m1} (℃)	T_{m2} (℃)	ΔH_c (J/g)
PA6	0	215.50	220.62	54.08
	1	215.54	220.07	51.40
	2	213.86	219.92	50.51
	4	215.46	219.76	53.04
	8	214.72	219.34	51.45
	12	213.14	218.61	51.28
PA6/PEA	0	214.74	220.80	52.39
	1	218.25	222.24	47.13
	2	215.55	221.62	46.77
	4	214.75	220.93	46.37
	8	214.47	220.29	50.4
	12	217.98	220.64	49.05
PA6/PPA	0	213.85	200.62	50.84
	1	213.99	220.31	48.97
	2	214.96	220.36	51.72
	4	214.96	220.44	50.39
	8	214.61	220.40	49.46
	12	214.92	219.72	48.1

Table S13 Corresponding fragments of PEA thermal cracking-gas phase mass spectrometry

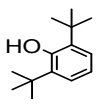
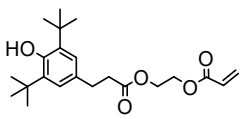
Time(min)	Fragment ion	Nominal mass	Nominal abundance
10.395		205	41.1,55.1,83.2,124.2,163.2 177.3,191.3,205.3
13.99		376	55.1,9.2,189.2,203.3,219.3 376.6

Table S14 Corresponding fragments of PPA thermal cracking-gas phase mass spectrometry

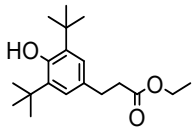
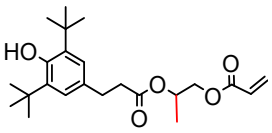
Time(min)	Fragment ion	Nominal mass	Nominal abundance
11.767		306	57.2，147.2，161.2，189.2，203.2，219.3，251.5，306.5
13.957		390	55.1，113.2，189.2，203.3，219.4，232.4，390.6

Table S15 Fragments corresponding to PA6/PEA cleavage mass spectra

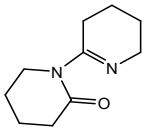
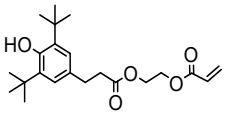
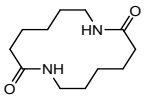
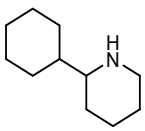
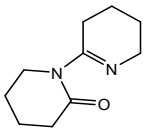
Time(min)	Fragment ion	Nominal mass	Nominal abundance
8.314		113	30.1,41.1,55.1,85.1,113.2
11.332		208	41.1,55.1,69.1,96.1,151.2,180.3,208.3
13.097,13.151,13.892,13.936		376(377)	55.1,57.1,139.2,147.2,168.2,189.2,203.3,216.2,219.3,232.2,265.3,336.5,377.3,390.5
14.317		226	30.1,41.1,55.1,114.2,198.3 226.4

Table S16 Fragments corresponding to PA6/PPA cleavage mass spectra

Time(min)	Fragment ion	Nominal mass	Nominal abundance
8.314		113	30.1,41.1,55.1,85.1,113.2
11.321		151	41.1,55.1,69.1,96.1,151.2,180.3,208.3

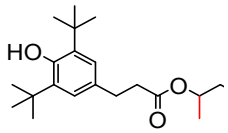
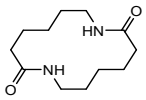
12.45,12.60, 13.18,13.968		376	28.1,41.1,55.1,57.2,84.1,99.1,147. 2,161.2,167.2,189.2,203.2,219.3,2 51.5,232.2,322.2,376.5
14.328		226	30.1,41.1,55.1,114.2,198.3 226.4

Table S17 Fragments corresponding to PA6 cleavage mass spectra

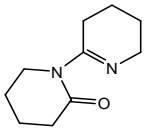
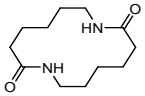
Time(min)	Fragment ion	Nominal mass	Nominal abundance
8.537		113	30.1, 41.1, 55.1 ,85.1 ,113.2
11.446		208	41.1,55.1,69.1,96.1,137.2,151.2 165.3,180.3,208.3
13.999		226	30.1,41.1,55.1,114.2,198.3,226. 3

Table S18 Percentage of PEA and PPA in PA6 for different aging days

	0D (%)	4D (%)	12D (%)
PEA	0.98	0.62	0.42
PPA	1.98	0.78	0.60

Table S19 PEA and PPA corresponding mobility

Time (Day)	1	2	3	4	5	6	7	8
PEA	3.76	4.14	4.70	4.85	5.34	6.27	6.44	6.75
PPA	3.98	4.07	4.08	4.15	4.33	4.90	5.73	5.77

References

1 C. Sánchez-Moreno, *Food Sci. Technol. Int.*, 2002, **8**, 121-137.

2 Tulsi Ojha, Susmita Limbu, Prakash Man Shrestha, Suresh Prasad Gupta and K.B. Rai, *Himalayan Journal of Science and Technology*, 2023, 38-49.