

Manufacturing Process Significantly Impacts the Rate of Degradation of Polylactic Acid (PLA) under Controlled Composting Conditions

Supplementary Material

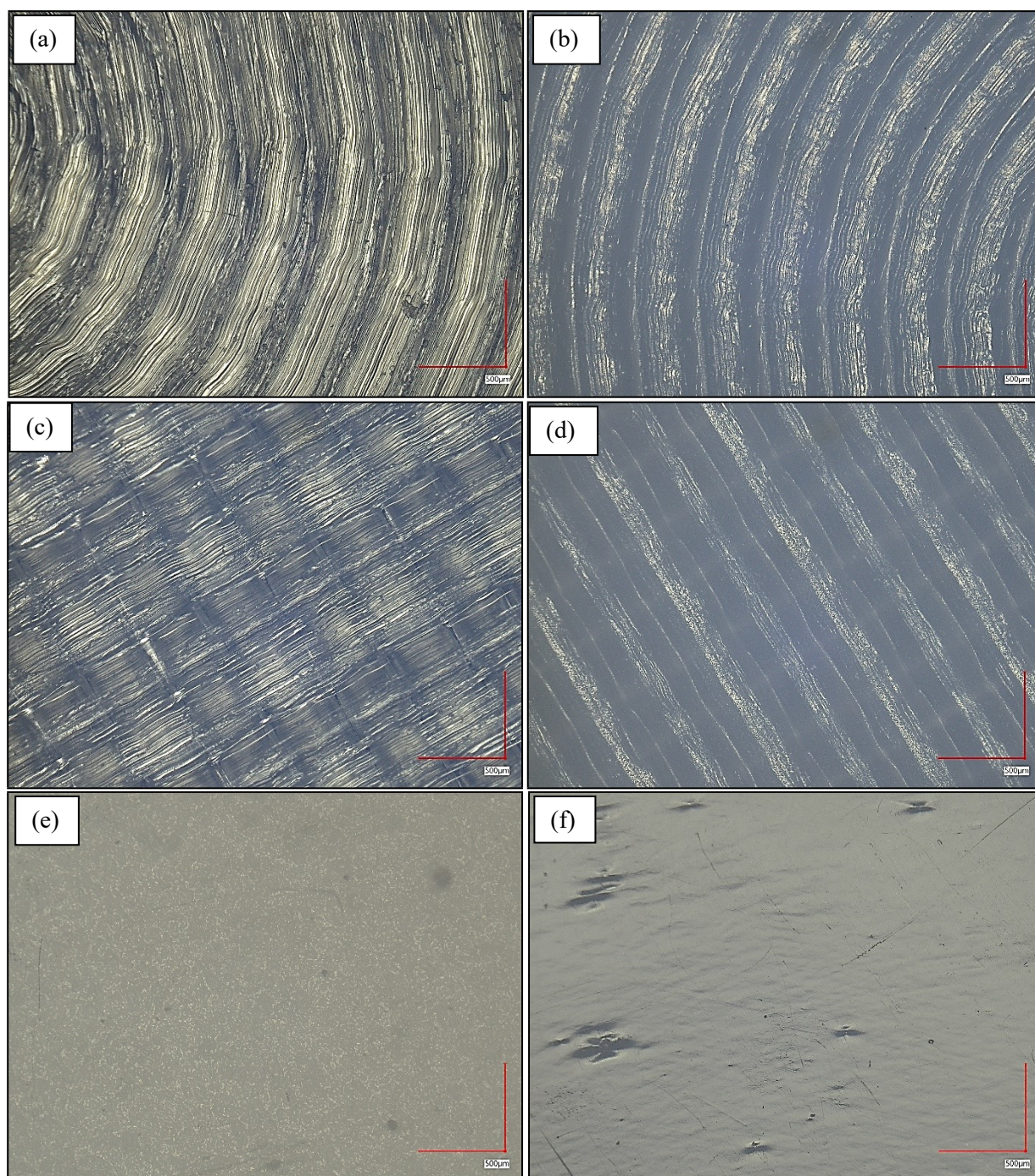


Figure S1. Optical micrographs of PLA coupons prior to composting. Red line indicates 500 μm . (a) 3D_C, (b) 3D_C_A, (c) 3D_Z, (d) 3D_Z_A, (e) IM, (f) IM_A.

	3D_C	3D_C A	3D_Z	3D_Z A	IM	IM A
% crystallinity	0.4 ± 0.1	0.3 ± 0.2	0.2 ± 0.1	0.2 ± 0.1	4.7 ± 1.1	1.8 ± 0.4

Table S1. Percentage crystallinity of PLA coupons before composting.

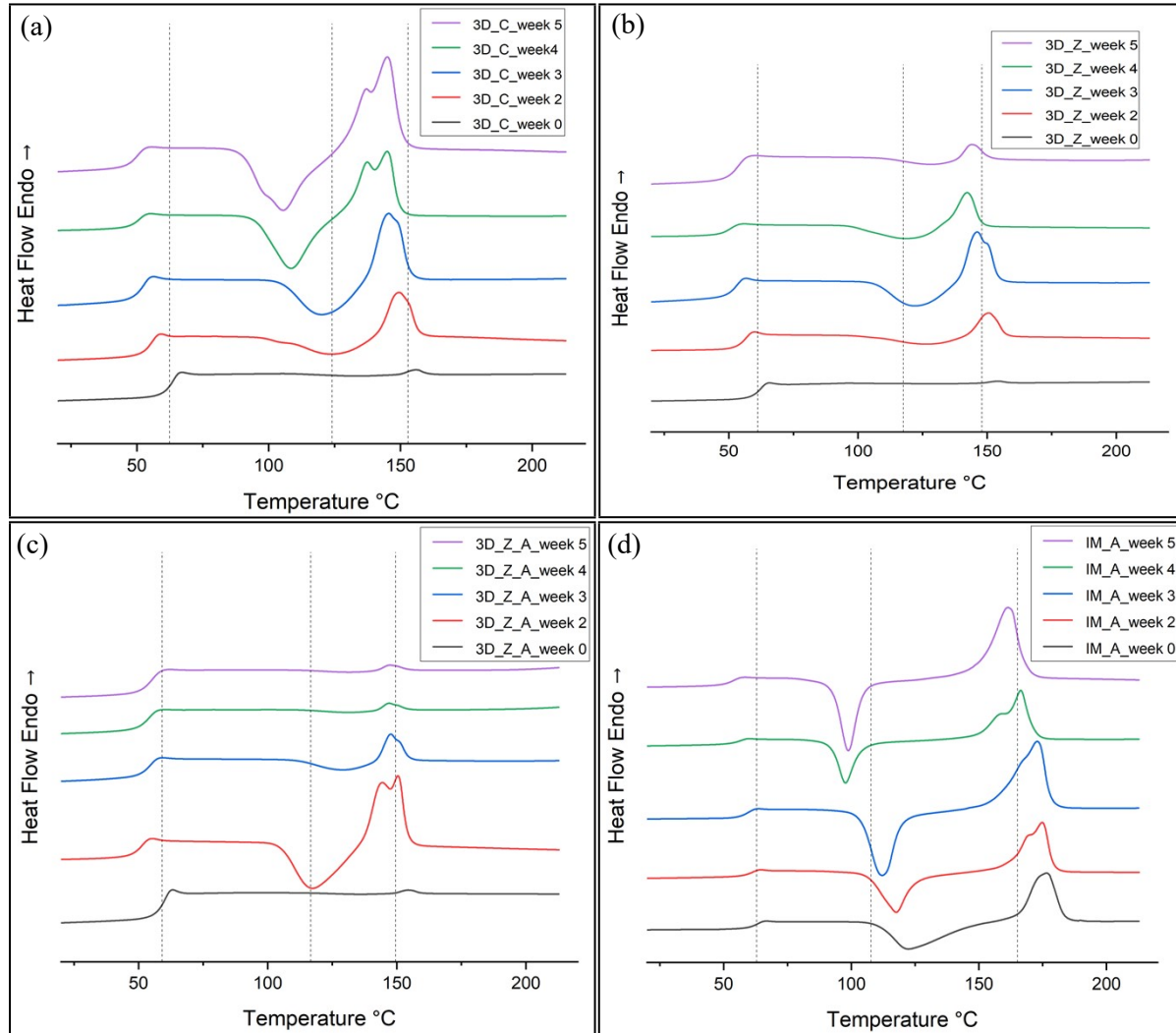


Figure S2. Thermograph of PLA coupons during composting. Dashed lines indicate the thermal transition temperatures of PLA coupons before composting trials (week 0). (a) 3D_C, (b) 3D_Z, (c) 3D_Z_A, (d) IM.

0 weeks	3D_C	3D_C_A	3D_Z	3D_Z_A	IM	IM_A
T _g °C	62.43 ± 1.89	59.67 ± 1.21	61.24 ± 1.56	59.15 ± 1.67	62.39 ± 0.19	63.01 ± 0.28
T _{cc} °C	124.08 ± 2.01	119.98 ± 1.45	117.52 ± 1.87	116.65 ± 2.21	110.17 ± 0.16	107.75 ± 0.01
ΔH _{cc} J/g	-0.34 ± 0.12	-0.28 ± 0.12	-0.50 ± 0.23	-0.30 ± 0.14	-38.94 ± 1.74	-42.01 ± 1.61
T _m °C	152.92 ± 1.78	148.24 ± 1.46	148.02 ± 1.98	149.50 ± 1.79	165.72 ± 0.10	165.12 ± 0.08
ΔH _m J/g	0.75 ± 0.34	0.62 ± 0.24	0.63 ± 0.21	0.52 ± 0.23	43.26 ± 1.17	43.64 ± 1.53
2 weeks	3D_C	3D_C_A	3D_Z	3D_Z_A	IM	IM_A
T _g °C	54.93 ± 2.01	49.41 ± 1.87	55.64 ± 0.31	50.84 ± 2.56	61.74 ± 1.63	60.54 ± 0.31
T _{cc} °C	99.84 ± 2.91	102.75 ± 2.89	102.92 ± 0.56	103.15 ± 1.45	99.64 ± 1.34	104.01 ± 0.56
ΔH _{cc} J/g	-11.36 ± 0.47	-21.57 ± 3.78	-7.00 ± 0.33	-24.02 ± 0.89	-36.07 ± 1.90	-45.43 ± 0.33
T _m °C	142.33 ± 0.98	136.56 ± 0.89	142.92 ± 0.71	136.24 ± 1.10	164.69 ± 1.93	156.25 ± 0.71
ΔH _m J/g	11.64 ± 1.45	23.42 ± 3.79	7.95 ± 2.11	25.84 ± 0.45	47.94 ± 2.47	48.52 ± 2.11
3 weeks	3D_C	3D_C_A	3D_Z	3D_Z_A	IM	IM_A
T _g °C	51.20 ± 1.87	51.36 ± 1.56	51.78 ± 1.12	53.72 ± 2.34	60.85 ± 1.89	58.70 ± 1.23
T _{cc} °C	104.85 ± 2.56	104.55 ± 1.78	104.74 ± 1.89	112.19 ± 1.78	97.70 ± 1.58	101.03 ± 0.89
ΔH _{cc} J/g	-18.11 ± 0.89	-13.48 ± 0.54	-15.67 ± 0.78	-5.17 ± 0.92	-44.94 ± 2.34	-46.78 ± 1.21
T _m °C	137.56 ± 1.56	139.50 ± 1.90	139.42 ± 1.67	141.23 ± 1.34	164.74 ± 1.56	153.13 ± 0.99
ΔH _m J/g	19.08 ± 1.34	13.87 ± 0.78	16.47 ± 1.01	6.53 ± 0.34	47.53 ± 1.99	56.66 ± 1.09
4 weeks	3D_C	3D_C_A	3D_Z	3D_Z_A	IM	IM_A
T _g °C	50.04 ± 1.47	55.84 ± 2.12	49.88 ± 1.42	53.63 ± 2.12	62.15 ± 1.45	55.5 ± 1.56
T _{cc} °C	93.63 ± 2.11	112.70 ± 1.89	96.22 ± 1.34	113.69 ± 1.78	106.21 ± 1.75	88.74 ± 1.23
ΔH _{cc} J/g	-28.20 ± 0.91	-0.93 ± 0.23	-11.36 ± 0.91	-0.76 ± 0.23	-48.08 ± 2.21	-33.94 ± 1.45
T _m °C	127.07 ± 1.89	142.42 ± 2.78	132.29 ± 1.94	141.94 ± 1.67	157.07 ± 1.85	148.76 ± 1.34
ΔH _m J/g	34.17 ± 2.04	1.43 ± 0.89	14.62 ± 0.98	1.48 ± 0.78	56.09 ± 2.98	57.17 ± 0.98
5 weeks	3D_C	3D_C_A	3D_Z	3D_Z_A	IM	IM_A
T _g °C	49.76 ± 0.87	55.32 ± 1.34	52.90 ± 1.87	54.46 ± 1.57	60.00 ± 1.90	53.12 ± 1.65
T _{cc} °C	88.66 ± 1.67	115.14 ± 1.53	111.07 ± 1.59	114.35 ± 1.46	102.01 ± 1.23	90.20 ± 0.99
ΔH _{cc} J/g	-31.59 ± 1.34	-0.35 ± 0.14	-1.20 ± 0.63	-0.40 ± 0.28	-44.18 ± 1.83	-32.1 ± 1.23
T _m °C	128.45 ± 1.45	143.14 ± 1.74	138.10 ± 1.84	141.70 ± 1.93	152.98 ± 1.98	143.32 ± 1.54
ΔH _m J/g	33.38 ± 1.96	0.98 ± 0.62	3.00 ± 1.04	1.05 ± 0.74	55.43 ± 1.80	54.29 ± 1.12

Table S2. Thermal transitions of PLA coupons prior to and during composting.

Table S3. Mechanical properties of 3D printed dogbones prior to composting (week 0) and after 1 week of composting where measurement was possible using the Zwick 5kn SB13 universal testing machine.

PLA	Tensile strength (MPa)	Young's modulus (MPa)	Max elongation (%)
Week 0	51.53 ± 1.10	3468.33 ± 101.85	1.8 ± 0.1
Week 1	21.38 ± 3.50	3762.00 ± 313.83	0.5 ± 0.1
Rec-1	Tensile strength (MPa)	Young's modulus (MPa)	Max elongation (%)
Week 0	52.45 ± 4.65	3746.67 ± 140.42	1.6 ± 0.3
Week 1	26.62 ± 5.04	3915.33 ± 339.76	0.6 ± 0.1
Rec-2	Tensile strength (MPa)	Young's modulus (MPa)	Max elongation (%)
Week 0	48.67 ± 5.30	3587.00 ± 195.24	1.6 ± 0.2
Rec-3	Tensile strength (MPa)	Young's modulus (MPa)	Max elongation (%)
Week 0	35.90 ± 3.99	3633.25 ± 184.88	1.0 ± 0.1

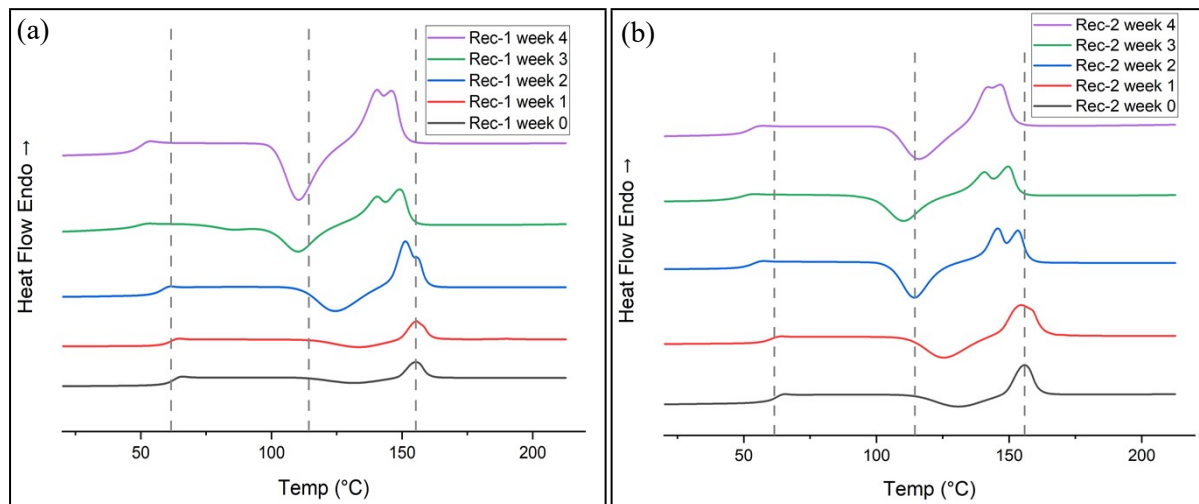
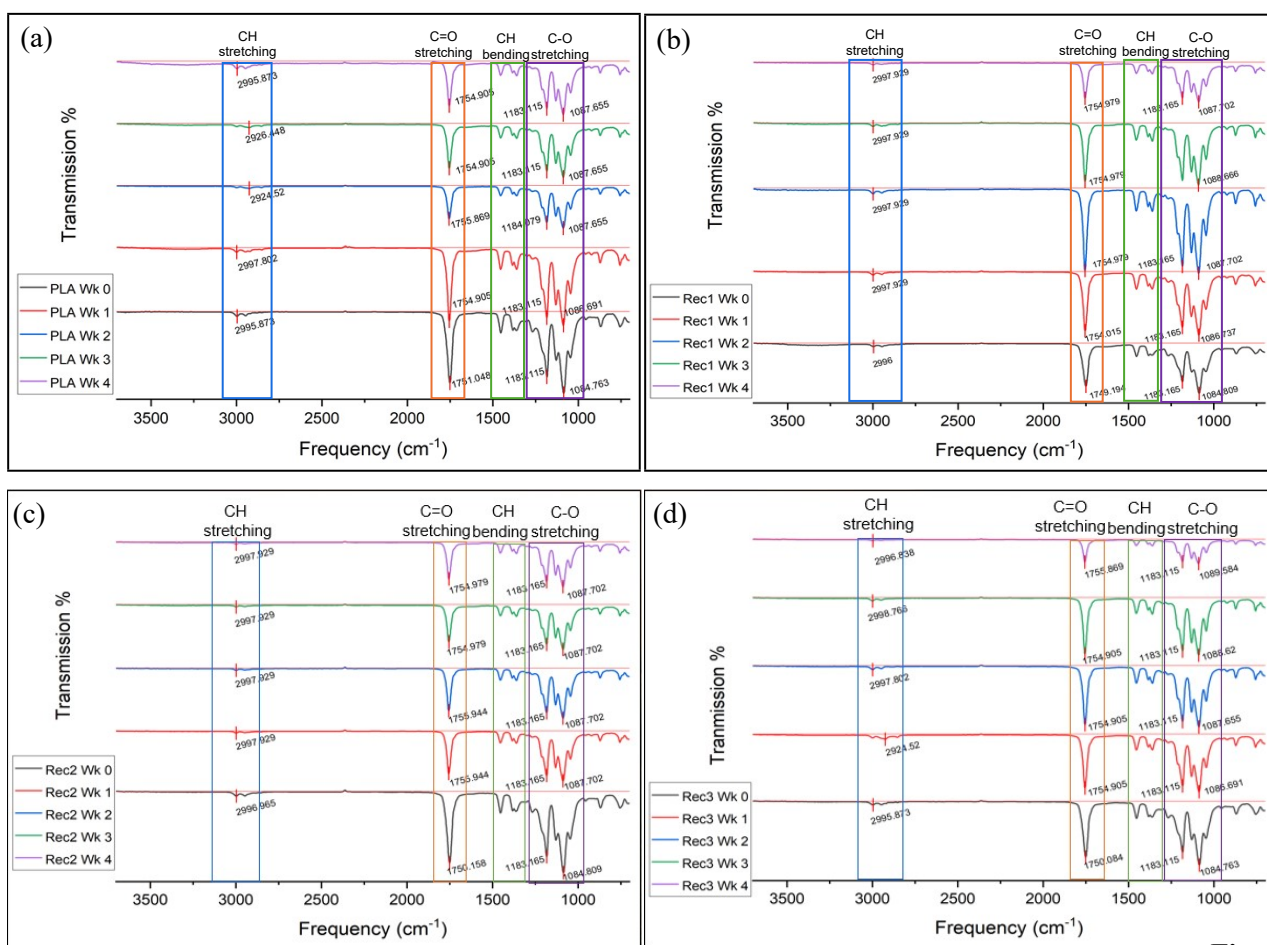


Figure S3. Thermograph of 3D printed dogbones prior to (week 0) and during composting. Dashed lines indicate the thermal transition temperatures of PLA coupons before composting trials (week 0). (a) Rec-1 and (b) Rec-2.

Table S4. Thermal transitions of 3D printed dogbones prior to and during composting.

PLA	Week 0	Week 1	Week 2	Week 3	Week 4
T _g °C	62.43 ± 1.64	61.83 ± 1.45	59.37 ± 1.97	49.34 ± 1.40	48.59 ± 1.09
T _{cc} °C	124.08 ± 1.34	121.03 ± 1.57	113.73 ± 1.84	99.79 ± 1.05	100.06 ± 1.98
ΔH _{cc} J/g	-0.34 ± 0.11	-1.37 ± 0.29	-7.27 ± 0.65	-20.63 ± 2.09	-37.23 ± 2.98
T _m °C	155.92 ± 1.89	157.02 ± 2.12	154.72 ± 2.65	150.70 ± 2.21	147.41 ± 1.78
T _m ' °C	-	-	-	142.94 ± 1.78	139.90 ± 1.59
ΔH _m J/g	0.75 ± 0.17	3.99 ± 0.98	8.62 ± 1.57	38.04 ± 2.54	38.73 ± 2.09
Rec-1	Week 0	Week 1	Week 2	Week 3	Week 4
T _g °C	61.68 ± 1.28	61.00 ± 1.56	57.68 ± 1.47	48.75 ± 1.83	49.08 ± 1.82
T _{cc} °C	114.38 ± 2.15	116.93 ± 1.94	110.61 ± 1.84	99.03 ± 1.19	100.08 ± 1.49
ΔH _{cc} J/g	-7.10 ± 1.02	-10.20 ± 0.57	-22.28 ± 1.38	-20.42 ± 1.84	-31.29 ± 1.54
T _m °C	155.34 ± 2.56	155.96 ± 2.03	151.40 ± 1.98	149.12 ± 1.79	146.05 ± 2.34
T _m ' °C	-	-	155.74 ± 1.57	140.62 ± 1.34	140.51 ± 1.56
ΔH _m J/g	7.21 ± 0.95	11.34 ± 1.05	25.98 ± 2.06	33.20 ± 1.83	34.78 ± 2.22
Rec-2	Week 0	Week 1	Week 2	Week 3	Week 4
T _g °C	61.53 ± 1.47	60.03 ± 1.78	52.88 ± 1.83	48.81 ± 1.71	52.05 ± 1.90
T _{cc} °C	114.51 ± 2.80	111.23 ± 2.94	104.95 ± 2.12	98.28 ± 1.92	104.80 ± 2.01
ΔH _{cc} J/g	-14.12 ± 1.28	-28.52 ± 1.94	-34.10 ± 1.45	-28.40 ± 1.89	-31.09 ± 1.36
T _m °C	155.89 ± 2.34	154.56 ± 2.62	153.40 ± 2.34	149.72 ± 1.93	146.81 ± 2.03
T _m ' °C	-	-	145.73 ± 1.57	140.79 ± 1.74	142.03 ± 1.38
ΔH _m J/g	17.69 ± 0.83	32.54 ± 1.32	38.47 ± 1.53	40.85 ± 1.74	35.72 ± 1.54
Rec-3	Week 0	Week 1	Week 2	Week 3	Week 4
T _g °C	61.01 ± 1.64	58.60 ± 1.73	45.95 ± 1.94	45.99 ± 1.39	49.01 ± 1.86
T _{cc} °C	113.78 ± 2.33	109.33 ± 1.84	96.27 ± 1.59	91.82 ± 1.21	102.37 ± 1.94
ΔH _{cc} J/g	-22.00 ± 1.95	-33.23 ± 1.53	-32.85 ± 2.43	-32.38 ± 1.23	-40.94 ± 2.79
T _m °C	154.49 ± 1.85	151.99 ± 1.94	148.51 ± 1.38	146.93 ± 0.94	141.50 ± 1.21
T _m ' °C	-	156.45 ± 2.54	137.96 ± 1.57	-	-
ΔH _m J/g	24.90 ± 0.63	34.34 ± 1.66	34.23 ± 1.78	41.22 ± 1.54	45.81 ± 1.74



Figure

S4. FTIR spectra of 3D printed dogbones prior to (week 0) and during composting. (a) PLA, (b) Rec-1, (c) Rec-2, (d) Rec-3.