Tapper, R., Longana, M., Yu, H., Hamerton, I., & Potter, K. (2018). Development of a closed-loop recycling process for discontinuous carbon fibre polypropylene composites. *Composites Part B: Engineering*, *146*, 222-231. https://doi.org/10.1016/j.compositesb.2018.03.048

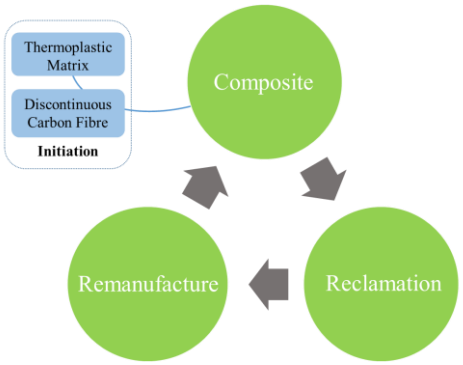


Fig. 1. The closed-loop methodology in brief; post initiation the cycle requires no additional material to propagate.

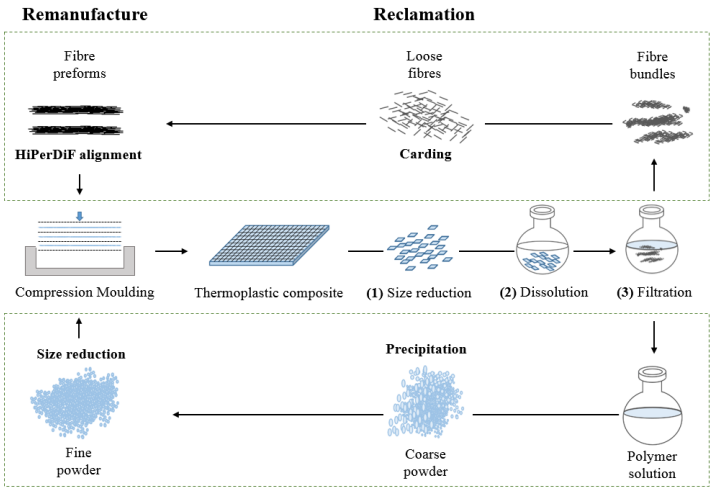


Fig. 2. A flow chart outlining the experimental detail of closed-loop recycling methodology, highlighting the reclamation and re-manufacturing processes.

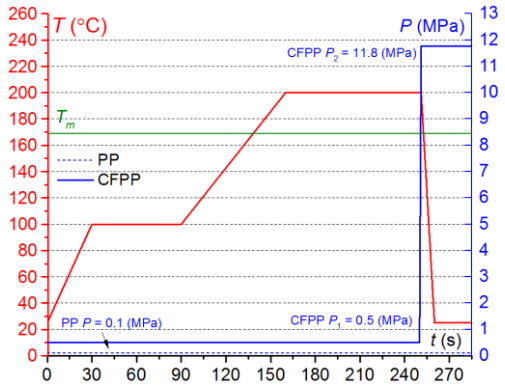
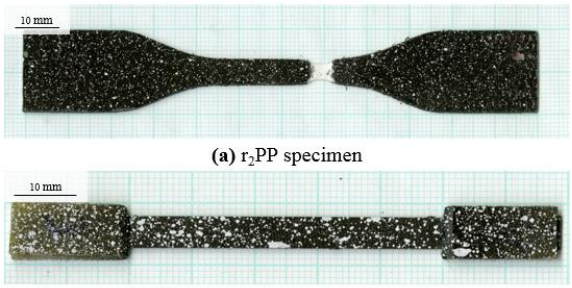


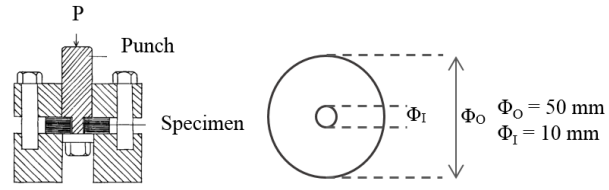
Fig. 3. Compression moulding schedule for PP and CFPP specimens.



(a) r_2PP specimen

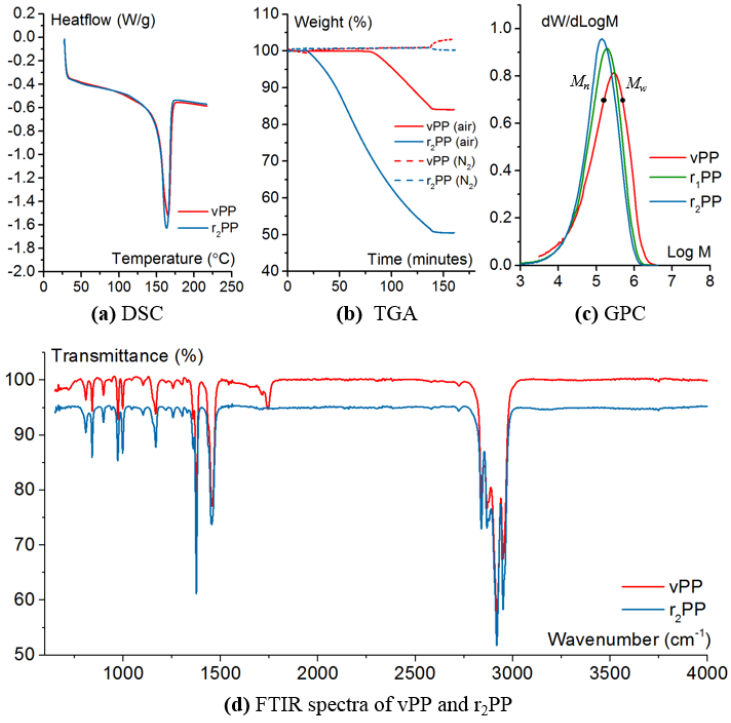
(b) vCFPP specimen

Fig. 4. High resolution scan of: (a) a necked r_2PP dumbbell specimen with speckled pattern. (b) vCFPP specimen with speckle pattern.



(a) Shear test punch tool **(b)** Shear disc

Fig. 5. ASTM D732 Punch shear test: (a) punch assembly and (b) Shear punch disc.



(a) DSC **(b)** TGA **(c)** GPC

(d) FTIR spectra of vPP and r_2PP

Fig. 6. a) DSC thermograms of vPP and r_2PP. b) Isothermal TGA thermographs of vPP and r_2PP, taken in air. c) GPC molecular weight distributions for vPP, r_1PP and r_2PP. d) FTIR spectra of vPP and r_2PP.

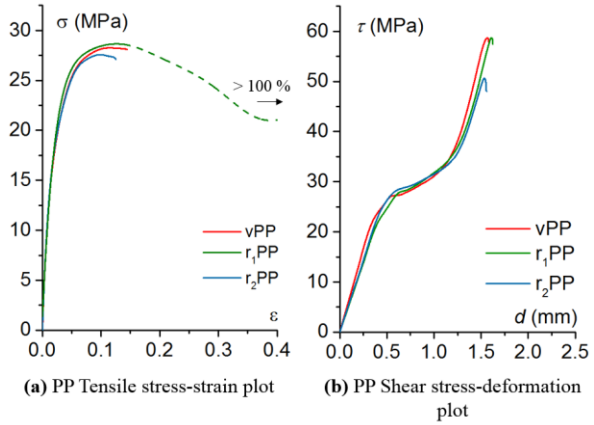


Fig. 7. (a) Stress-strain curves for PP after each recycling loop. (b) Stress-displacement plots for PP after each recycling loop.

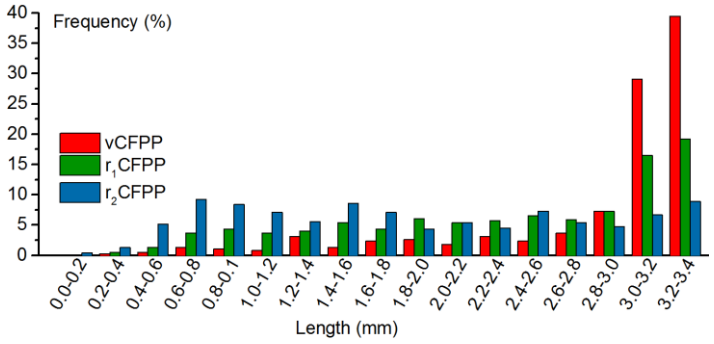
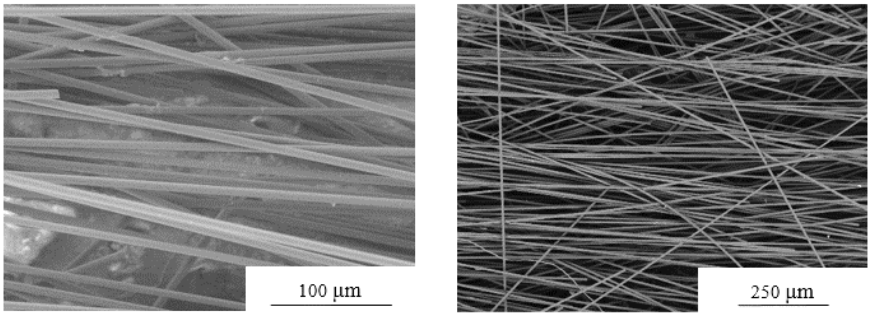
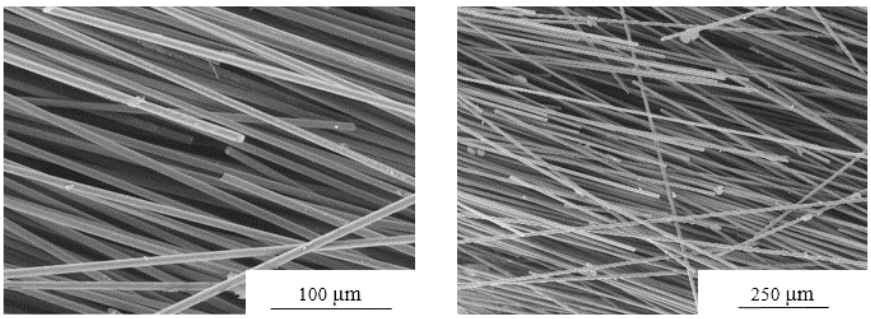


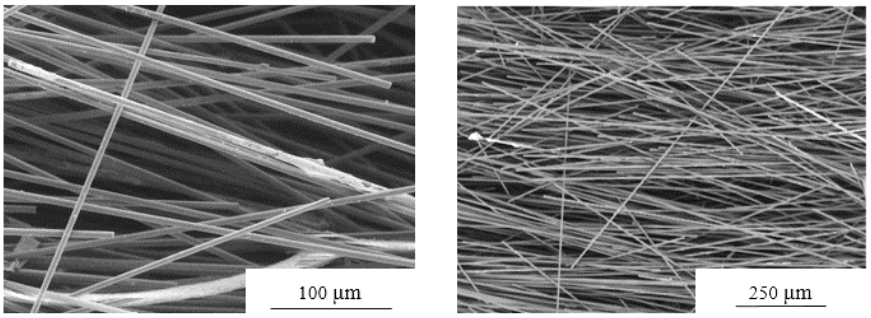
Fig. 8. Fibre length distributions of vCFPP, r_1CFPP and r_2CFPP showing percentages of fibres in effective fibre range.



(a) vCFPP fibres

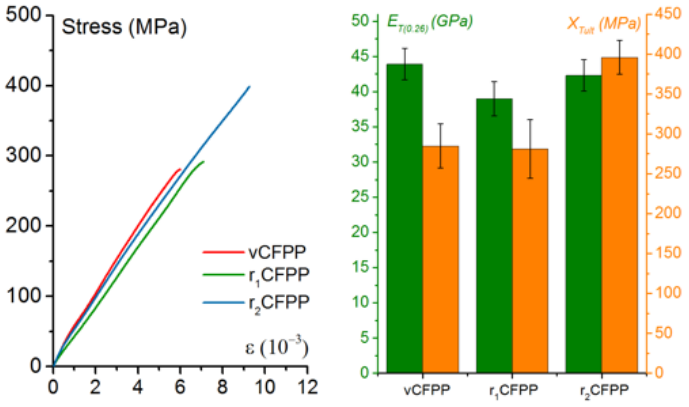


(b) r_1CFPP fibres



(c) r_2CFPP fibres

Fig. 9. SEM micrographs for; a) vCFPP, b) r_1CFPP and c) r_2CFPP.



(a) CFPP Tensile stress-strain plot **(b)** CFPP tensile data

Fig. 10. a) Stress-strain curves for CFPP specimens after each loop. b) Bar chart comparing the tensile stiffness (normalised to 26 % Vf_F) and ultimate tensile strength of CFPP after each recycling loop.

	Morphology	Density	M_P	T_g	Crystallinity	M_W	M_n	PDI
		g cm^{-3}	*°C*	*°C*	*%*	*g mol^{-1}*	*g mol^{-1}*	
PP	pellet	0.91	166	10	45	3.4 x 10^5	9.7 x 10^4	3.5

Table 1. Properties of polypropylene.

	Length	Density	Diameter	E_T	X_T
	mm	*g cm^{-3}*	*µm*	*GPa*	*MPa*
CF	3	1.82	7	225	4344

Table 2. Properties of carbon fibres.

	Shred Size	Solvent	Temperature	Time	Non-solvent	Concentration	Solvent Ratio	Fibre Yield	Matrix Yield
	mm^3		*°C*	*mins*		*% w/v*	*S:NS*	*%*	*%*
PP	100	xylene	135	180	acetone	15	1:3	-	90
CFPP	125	xylene	135	60	acetone	1	1:3	94	93

Table 3. Reclamation parameters for each feedstock material.

	CF mass	PP mass	Predicted Vf_F	Temperature	Pressure	Actual CF Vf_F	Flash
	mg	*g*	*%*	*°C*	*MPa*	*%*	*%*
PP	-	20	-	200	1	-	12
CFPP	123	0.200	25	200	11.8	30	16

Table 4. Remanufacture parameters, composite volume fractions and wastage.

	M_n	M_w	*PDI*
	x10^4 (g mol^{-1})	x10^5 (g mol^{-1})	
vPP	6.58 (1.0)*	3.28 (2.0)	4.87
r_1PP	6.30 (14)	2.21 (0.1)	3.59
r_2PP	6.00 (5.1)	1.95 (2.4)	3.35

* Coefficient of variance

Table 5. The GPC/SEC analysis of polypropylene after each recycling iteration.

	E_T	X_{Tult}	e_{Tult}	S	T_m	Crystallinity
	GPa	MPa	%	MPa	°C	%
vPP	1.38 (1.8)*	27.8 (1.5)	10.9 (4.9)	59.7 (3.8)	166 (0.3)	47.3 (4.2)
r_1PP	1.44 (6.9)	27.1 (4.7)	11.8 (9.0)	58.2 (5.4)	167 (0.3)	44.9 (0.9)
r_2PP	1.39 (6.7)	27.3 (5.8)	9.0 (16.5)	50.4 (6.4)	165 (1.7)	50.4 (2.3)

* Coefficient of variance

Table 6. The material characterisation data for PP after each recycling loop.

	E_T	Vf_F	E_T *(0.26)*	e_{Tult}	X_{Tult}	ρ
	GPa	*(%)*	*MPa*	*%*	*MPa*	*g cm^{-1}*
vCFPP	44.0 (5.0)*	26.2 (8.4)	43.9 (5.1)	0.69 (12)	285 (9.7)	1.00 (2.6)
r_1CFPP	39.2 (6.0)	26.2 (4.6)	39.0 (5.5)	0.70 (8.8)	281 (13)	1.00 (2.5)
r_2CFPP	42.8 (5.6)	26.3 (3.6)	42.3 (5.1)	0.99 (4.4)	396 (5.4)	1.00 (4.3)

Table 7. The mechanical performance of CFPP specimens after each recycling iteration.