Influence of Ambient Temperature and Crystalline Structure on Fracture Toughness and Production of Thermoplastic by Enclosure FDM 3D Printer

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Supplementary Data

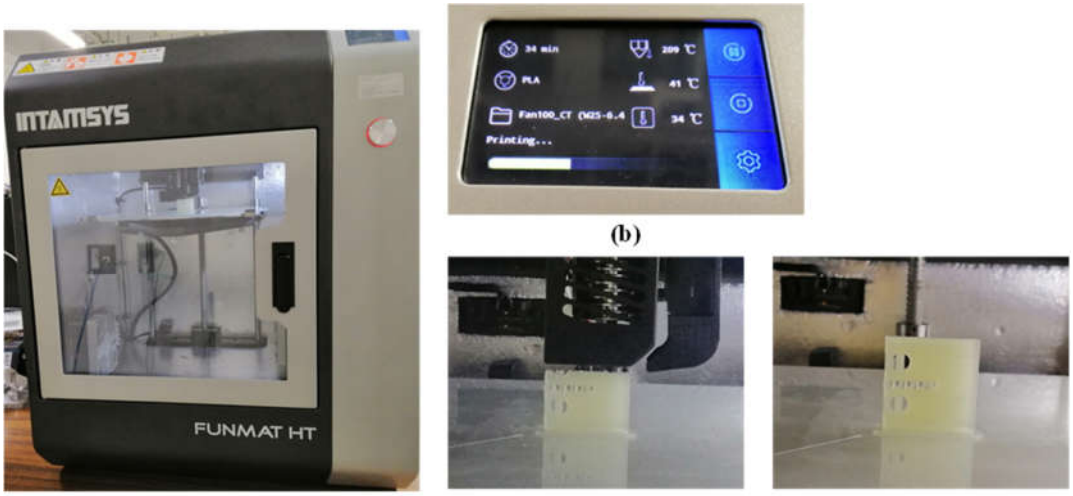

Figure S1. (a) Photograph of FUNMAT HT enclosure FDM 3D printer, (b) Control panel and display of the printer, (c) Nozzle head and cooling fan during printing compact tension specimen, and (d) 3D printed compact tension specimen

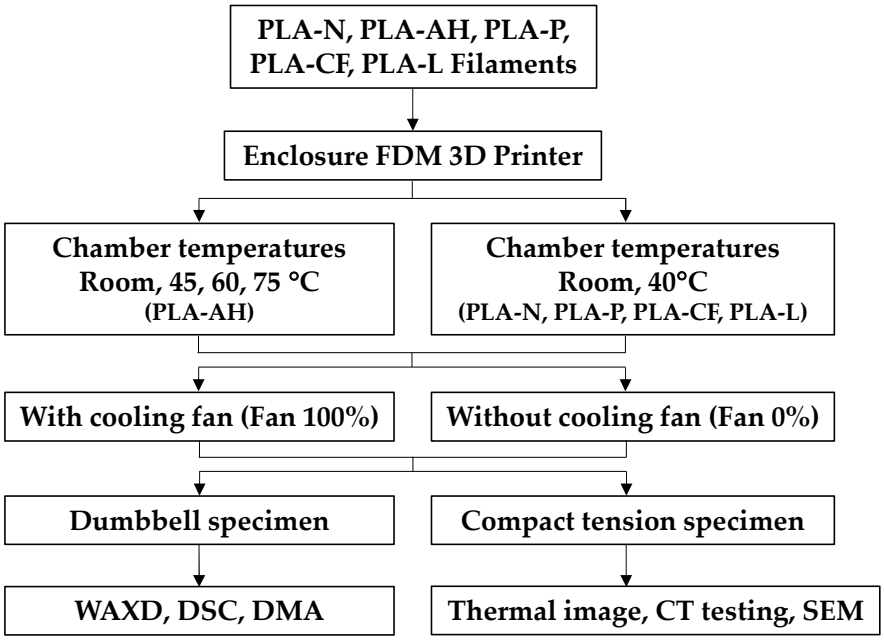

Figure S2. Experimental flow chart

Design of Experiments (DOE)

A full factorial design in possible combinations of levels of multiple factors was used for the experimental plan on statistic approach as represented in Table 2 by setting the chamber temperatures and the cooling fans as variables. The experimental plan and design matrix for the variable of fracture toughness of the PLA-AH and the PLA-N are shown in Tables S1 and S2, respectively. Overall, the experimental plan provided a clear and accurate description of the full factorial design method [48-50].

Table S1. Experimental plan and design matrix for the variable of fracture toughness of PLA-AH

Run order	Chamber temperature (°C)	Cooling fan (%)	Fracture toughness ($MPa \cdot m^{1/2}$)
1	25	0	184.28
2	25	100	98.71
3	45	0	204.83
4	45	100	113.35
5	60	0	205.49
6	60	100	123.57
7	60	0	205.49
8	75	0	206.66
9	75	100	121.79
10	25	0	184.99
11	25	100	90.06
12	45	0	203.11
13	45	100	116.48
14	60	0	207.81
15	60	100	116.68
16	60	0	207.81
17	75	0	194.53
18	75	100	131.19
19	25	0	198.18
20	25	100	99.5578
21	45	0	187.19
22	45	100	106.27
23	60	0	207.58
24	60	100	116.44
25	60	0	207.58
26	75	0	202.36
27	75	100	115.23

Table S2. Experimental plan and design matrix for the variable of fracture toughness of PLA-N

Run order	Chamber temperature (°C)	Cooling fan (%)	Fracture toughness (MPa·m$^{1/2}$)
1	40	100	109.72
2	40	0	169.24
3	25	0	154.28
4	25	100	85.87
5	40	100	102.43
6	40	0	176.48
7	25	0	163.90
8	25	100	88.40
9	40	100	86.22
10	40	0	187.45
11	25	0	175.56
12	25	100	88.36

The full factorial design was carried out to determine the relationship between responses and input parameters. The independent variables are used to express the response functions for the fracture toughness. The main effects and the interactions of the factors on the response variable of interest can be expressed as [48]

$$\mu_{ij} = \mu + \tau_i + \beta_j + (\tau\beta)_{ij} \tag{S1}$$

Where μ_{ij} is the regression model.

ij = row and column treatments

μ = coefficients of the model

τ = factor A

$\tau\beta$ = interaction between factors A and B

Mathematics and Statistics Analysis

Statistical analysis is performed to find the terms in the analysis of variance (ANOVA) that have a significant effect on fracture toughness.

Table S3. Analysis of variance of PLA-AH

Analysis of Variance

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Model	4	53452.6	13363.2	353.54	0.000
Linear	4	53452.6	13363.2	353.54	0.000
Chamber Temp	3	1729.6	576.5	15.25	0.000
Cooling Fan	1	48742.6	48742.6	1289.57	0.000
Error	22	831.5	37.8		
Lack-of-Fit	3	166.2	55.4	1.58	0.227
Pure Error	19	665.3	35.0		
Total	26	54284.2			

Model Summary

S	R-sq	R-sq(adj)	R-sq(pred)
6.14798	98.47%	98.19%	97.59%

The coded unit regression model allows for the examination of the relationship between the response variable and multiple independent variables. Therefore, the process optimization and quality control on the fracture toughness of PLA-AH can be expressed as the following.

$$\begin{aligned} Fracture\ toughness \\ &= 155.74 - 13.11(Chamber\ temp25) - 0.54(Chamber\ temp45) \\ &+ 7.43(Chamber\ temp60) + 6.22(Chamber\ temp75) \\ &+ 43.30(Cooling\ fan0) - 43.30(Cooling\ fan100) \end{aligned} \tag{S2}$$

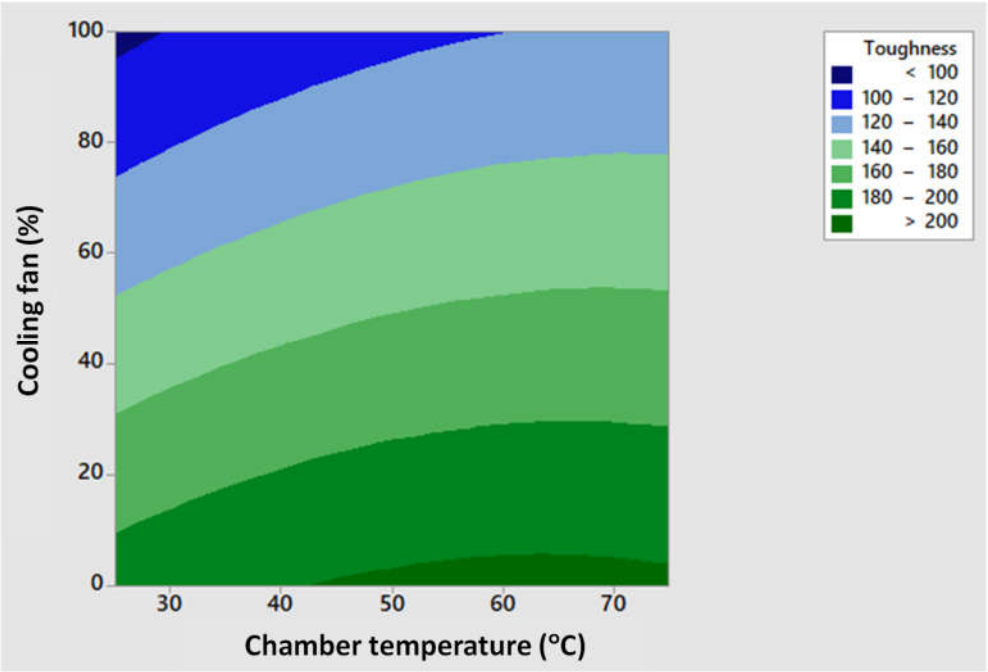

Figure S3. Contour plot between cooling fan and chamber temperature for fracture toughness of PLA-AH

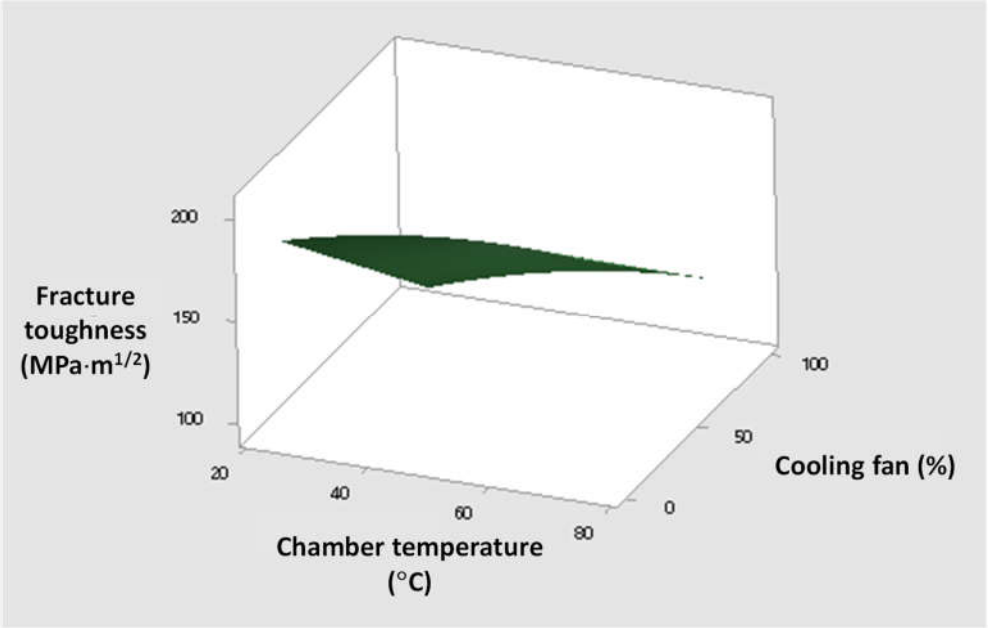

Figure S4. Surface response between cooling fan and chamber temperature on fracture toughness of PLA-AH

Table S4. Analysis of variance of PLA-N

Analysis of Variance

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Model	2	18559.2	9279.6	121.07	0.000
Linear	2	18559.2	9279.6	121.07	0.000
Chamber Temp	1	470.9	470.9	6.14	0.035
Cooling Fan	1	18088.3	18088.3	236.00	0.000
Error	9	689.8	76.6		
Lack-of-Fit	1	1.1	1.1	0.01	0.912
Pure Error	8	688.7	86.1		
Total	11	19249.0			

Model Summary

S	R-sq	R-sq(adj)	R-sq(pred)
8.75476	96.42%	95.62%	93.63%

The mathematical model for the fracture toughness of the PLA-N in the terms of the coded factors is presented as the following.

$$Fracture\ toughness = 144.0 + 0.835(Chamber\ temp) - 0.7765(Cooling\ fan) \quad \text{(S3)}$$

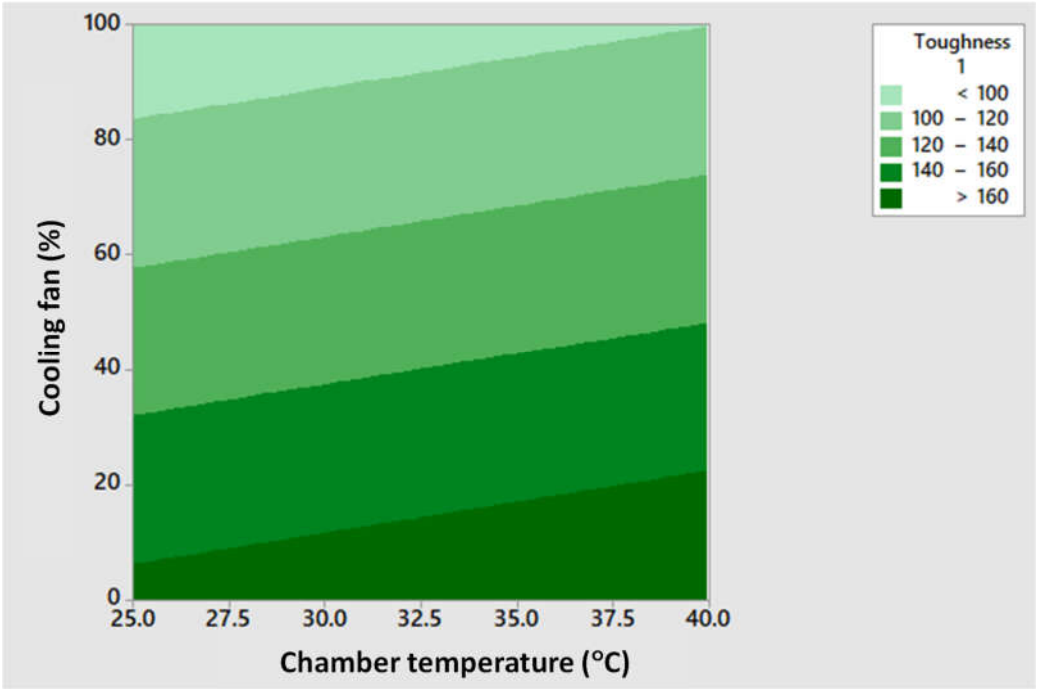

Figure S5. Contour plot between cooling fan and chamber temperature for fracture toughness of PLA-N

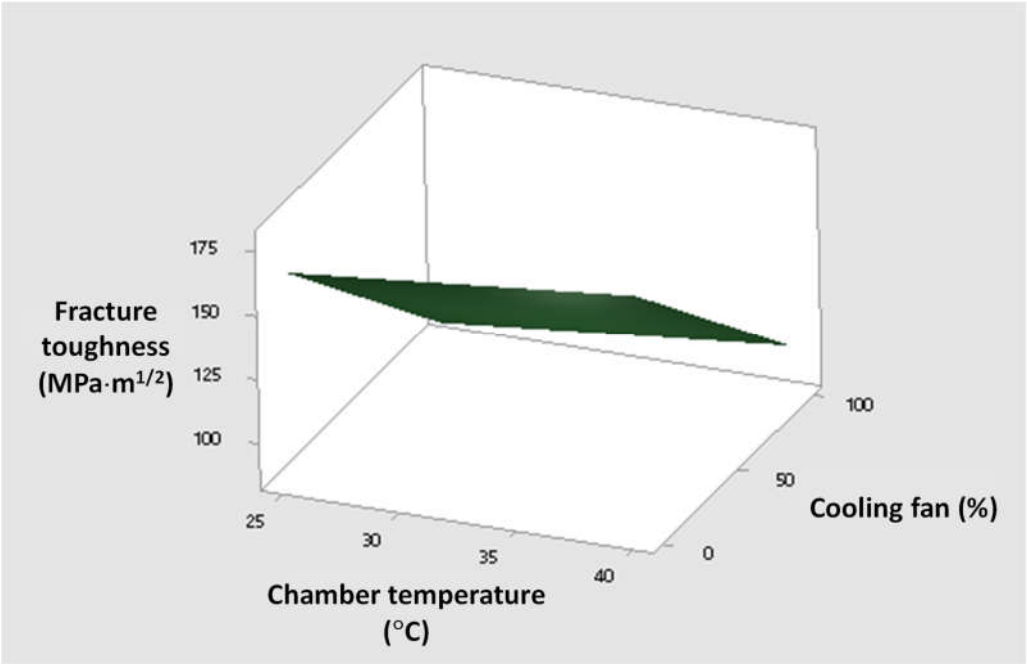

Figure S6. Surface response between cooling fan and chamber temperature on fracture toughness of PLA-N