**Supplementary information**

**Additive manufacturing-enabled shape transformations via FFF 4D printing**

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Figure S1: An optical image showing the printed part with raft and brim

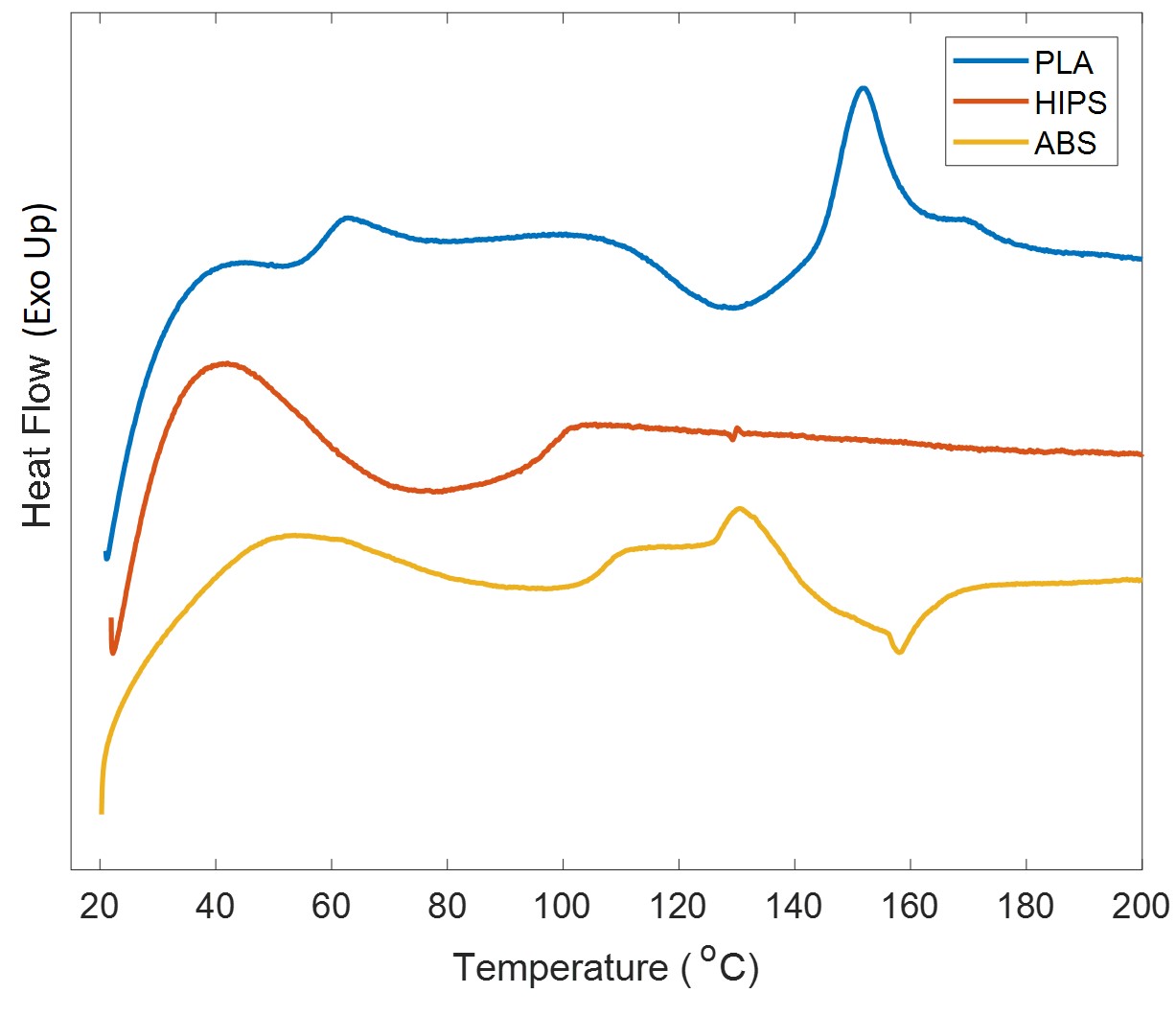


Figure S2: DSC thermo-graphs for different 3D printing filaments



Figure S3: Effect of temperature on the tensile performance of different 3D printed thermoplastics, a)PLA, b)HIPS and c)ABS

Table S1: Effect of temperature on the mechanical properties of various materials

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| Material | Property | Temperature (°C) | | | |
| 22 | Tg-20 | Tg | Tg+20 |
| PLA | Modulus (MPa) | 1440 ± 13.9 | 213 ± 27.3 | 59 ± 4.7 | 12.5 ± 2.7 |
| Strength (MPa) | 47.5 ± 4 | 11.3 ± 1.8 | - | - |
| Failure Strain (%) | 7.1 ± 2.1 | ± 23 | >500% | >500% |
| HIPS | Modulus (MPa) | 771 ± 47.8 | 652 ± 48.2 | 42.5 ± 4.5 | 3.1 ± 1.1 |
| Strength (MPa) | 12.6 ± 2.1 | 8.2 ± 1.3 | 1.3 ± 0.8 | - |
| Failure Strain (%) | 27 ± 3.9 | 65 ± 4.8 | >500% | >500% |
| ABS | Modulus (MPa) | 1124 ± 7.9 | 801 ± 48.5 | 512 ± 16.4 | 25.8 ± 3.8 |
| Strength (MPa) | 37.3 ± 3.7 | 17.3 ± 3.8 | 13.1 ± 2.1 | - |
| Failure Strain (%) | 6.2 ± 1.6 | 9.1 ±1.2 | 372 ± 37 | >500% |

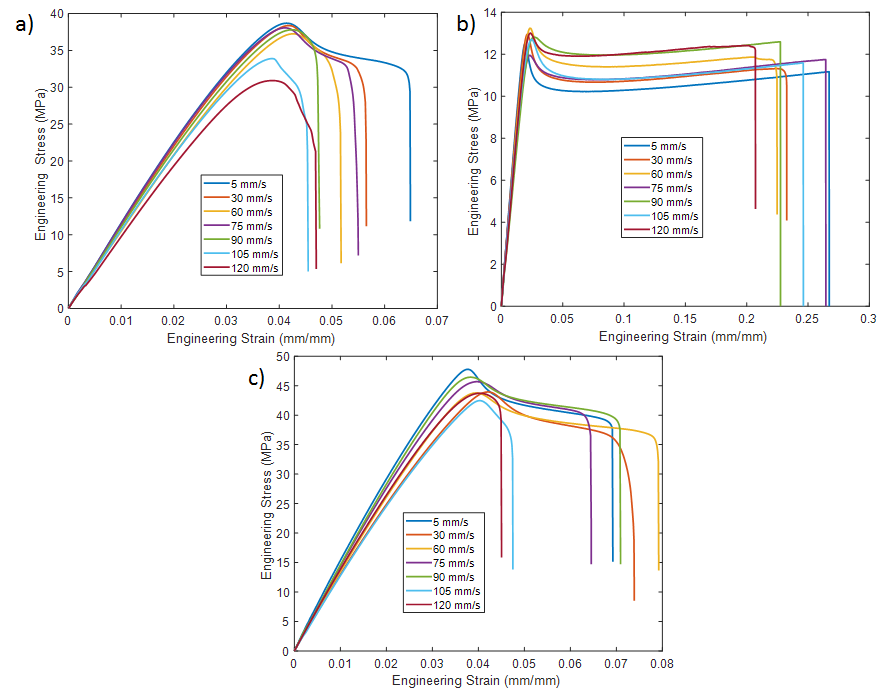


Figure S4: Effect of printing speed on the tensile performance of different 3D printed thermoplastics at room temperature. a)PLA, b)HIPS and c)ABS

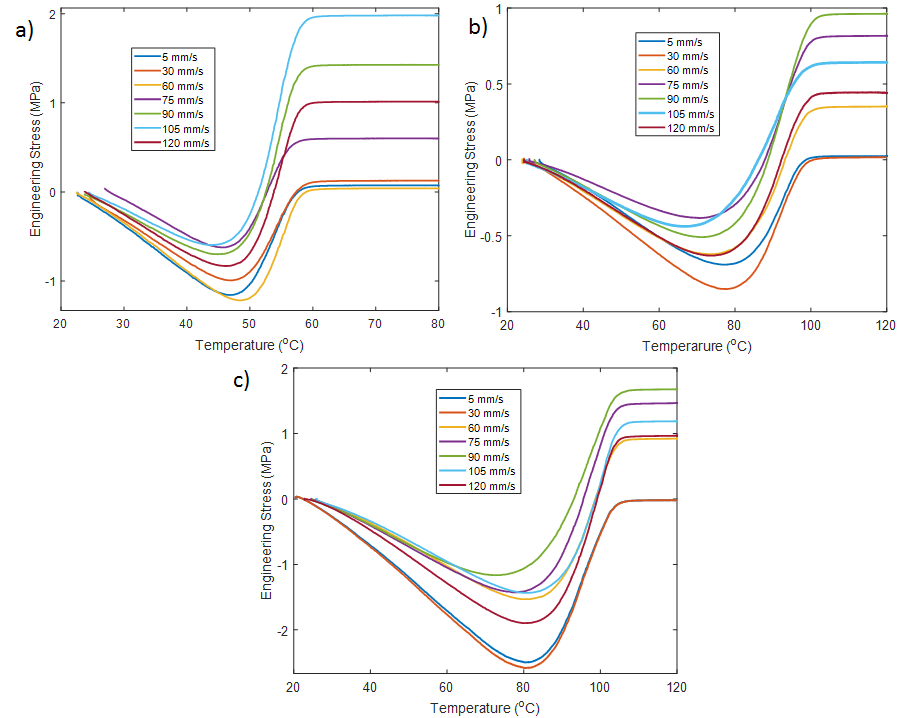


Figure S5: Effect of printing speed on the recovery stress of different 3D printed thermoplastics a)PLA, b)HIPS and c)ABS

**S1. Parameter determination:**

In this section we present a detailed procedure to obtain the various material parameters for the constitutive model.

1. Glass transition temperature, : Obtained directly from the DSC experiments (Figure S2.)
2. Volumetric CTE, : Initially, the thermal expansion curves (strain vs. temperature) is obtained by a push rod dilatometer and curve fitted to a second order polynomial (Figure S6). The equation is differentiated to obtain the linear CTE. Under isotropic assumptions, the volumetric CTE is taken as the three times the linear CTE.
3. Glassy state shear modulus,: From the tensile tests at room temperature (Table S1) considering a standard Poisson ratio of 0.4
4. Glassy state Lame's constant,: From the tensile tests at room temperature (Table S1) considering a standard Poisson ratio of 0.4
5. Rubbery state shear modulus, : From the tensile tests at Tg+20 (Table S1) considering a standard Poisson ratio of 0.5 (incompressibility)
6. Bulk modulus,: From the tensile tests at room temperature (Table S1) considering a standard Poisson ratio of 0.4
7. Initial shear strength, : By calculating the strength from the tensile tests at room temperature (Table S1):
8. WLF parameters () and Structural relaxation time at, is obtained by fitting the heat flow equation to the DSC curves at the glass transition region. Detailed procedure can be found elsewhere [1].
9. , are obtained from curve fitting the predictions and experiments by minimizing following the error function [2];

Where N is the total no. of experimental data points, and are the predicted and experimental values for the th data point.

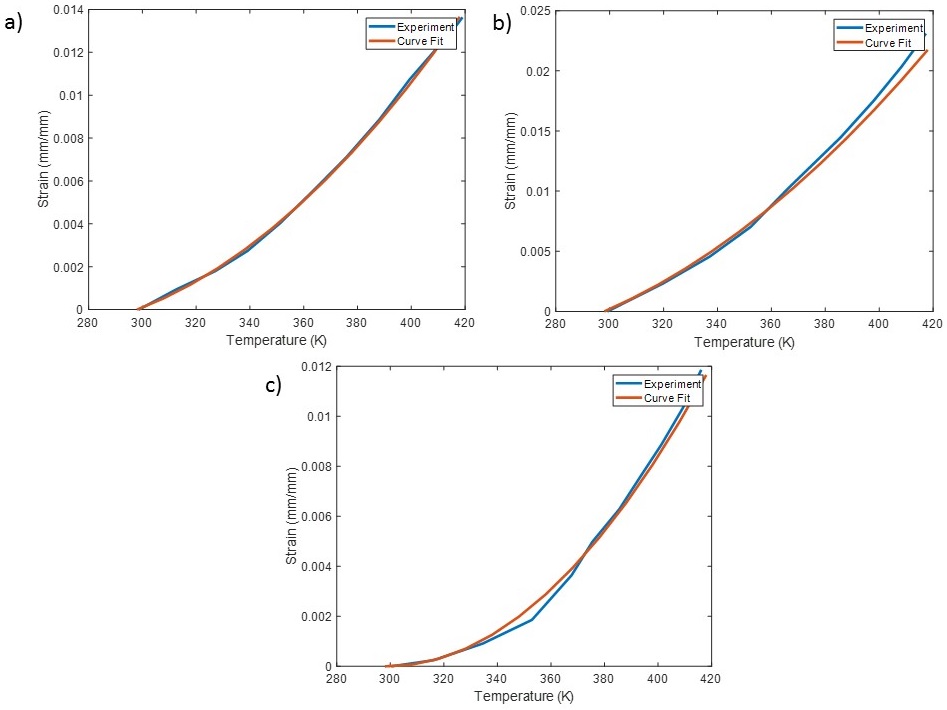


Figure S6: Thermal expansion curves of a)PLA, b)HIPS and c)ABS

**References:**

[1] R. Abishera, R. Velmurugan, K. N. Gopal, Reversible plasticity shape memory effect in epoxy/CNT nanocomposites-a theoretical study, *Compos Sci Technol*, **141**, 145-153 (2017).

[2] R. Abishera, R. Velmurugan, K. Nagendra Gopal, Free, partial, and fully constrained recovery analysis of cold-programmed shape memory epoxy/carbon nanotube nanocomposites: Experiments and predictions, ‎*J. Intell. Mater. Syst. Struct* , **29**(10), 2164-2176 (2018).