EXPANDED GRAPHITE TO ENHANCE THERMAL CONDUCTIVITY OF 3D PRINTED SHAPE-STABILIZED PHASE CHANGE MATERIALS IN HIGH DENSITY POLYETHYLENE

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Aim of the work

- Incorporation of organic **Phase Change Materials (PCMs)** into a **thermoplastic** matrix for 3D printing of structures for **passive cooling** of electronic devices
- Maximize **melting enthalpy** of the composite material
- Enhance **thermal conductivity**

Materials

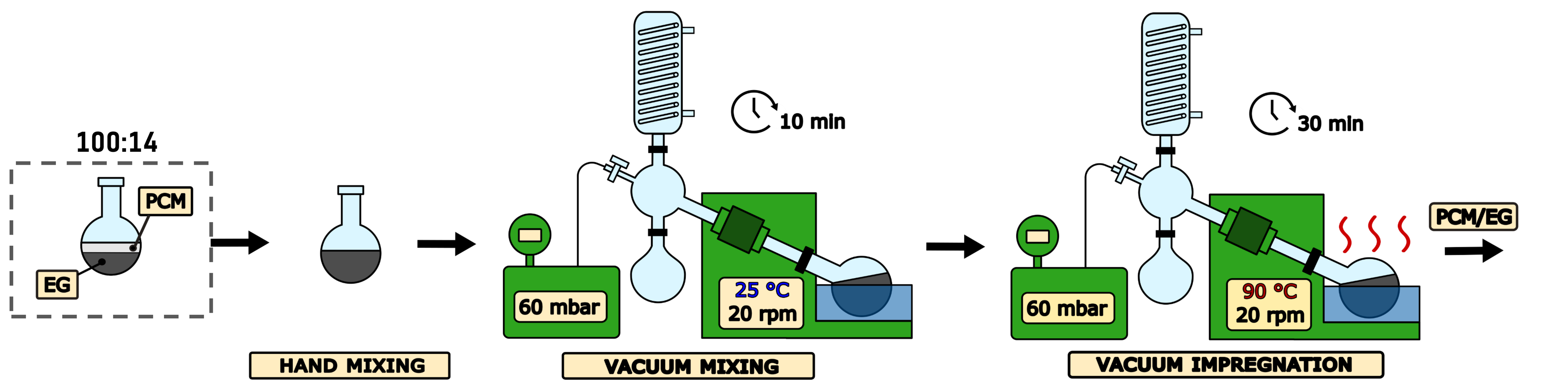
- **PCM** → **SA** stearic-palmitic acid mixture — Carlo Erba Reagents (Val De Ruil, France)
- **Matrix** → **HDPE**: High Density Polyethylene — PLASTENE® AD25, Poliplast S.p.A. (Casnigo, Italy)
- **"Filler"** → **EG**: Expanded Graphite — SGL Carbon GmbH (Meitingen, Germany)

Sample preparation

1) First shape stabilization

[1] Sacchet, S.; Valentini, F.; Benin, A.; Guidolin, M.; Po, R.; Fambri, L. Expanded Graphite (EG) Stabilization of Stearic and Palmitic Acid Mixture for Thermal Management of Photovoltaic Cells. *C* **2024**, *10*, 46. https://doi.org/10.3390/c10020046

[2] Sacchet, S.; Valentini, F.; Guidolin, M.; Po, R.; Fambri, L. Shape-Stabilized Phase Change Materials with Expanded Graphite for Thermal Management of Photovoltaic Cells: Selection of Materials and Preparation of Panels. *Appl. Sci.* **2025**, *15*, 4352. https://doi.org/10.3390/app15084352

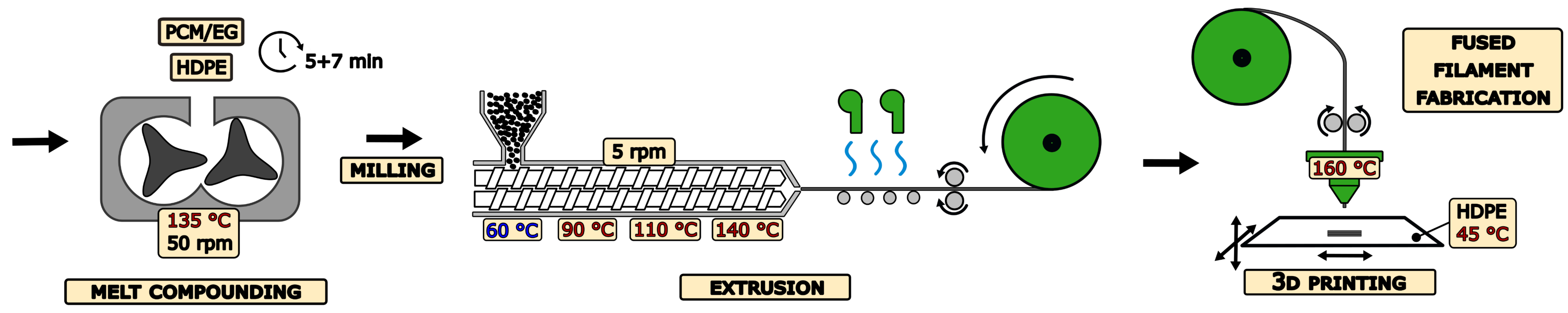


2) Second shape stabilization

[3] Sacchet, S.; Valentini, F.; Rizzo, C.; Po, R.; Fambri, L. High density polyethylene with phase change materials for thermal energy management. *Energy Mater.* **2025**, *5*, 500042. http://dx.doi.org/10.20517/energymater.2024.112

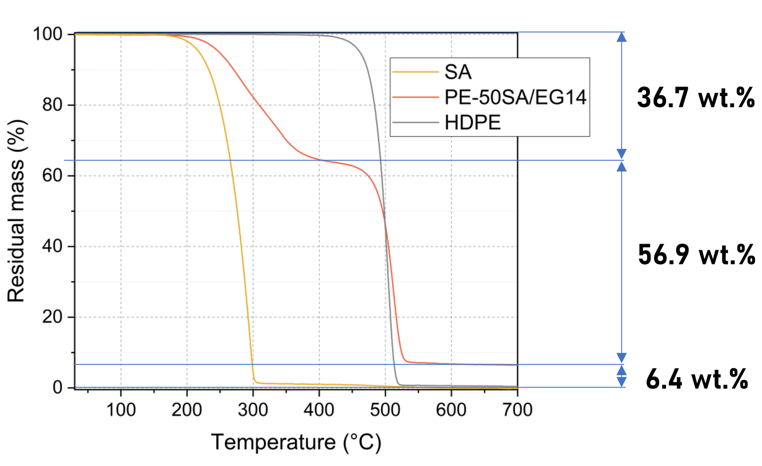
Nominal composition

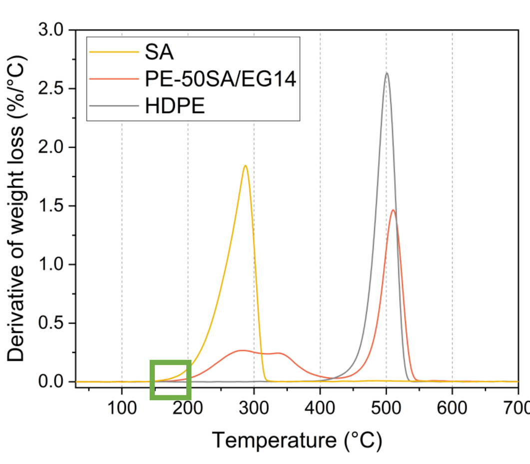
Sample	HDPE (wt.%)	SA (wt.%)	EG (wt.%)
PE-50SA/EG14	50	43.9	6.1



Results

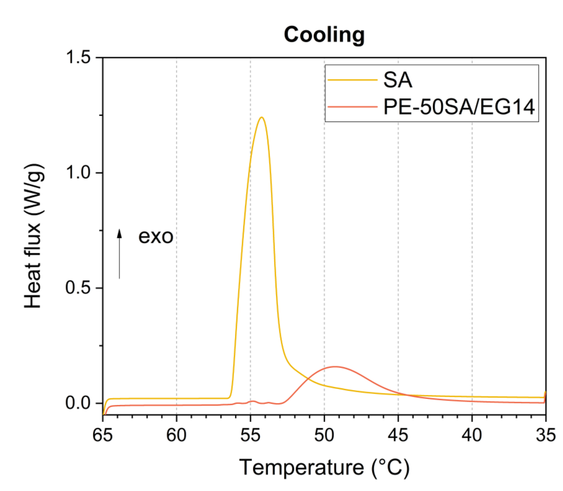
Thermogravimetric analysis (TGA)

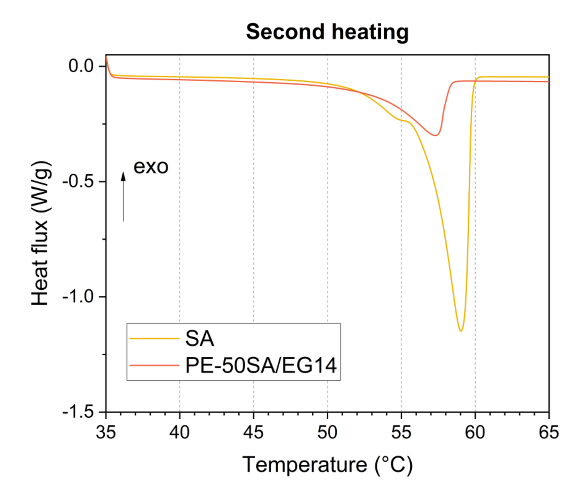




HDPE as matrix

Differential Scanning Calorimetry (DSC)



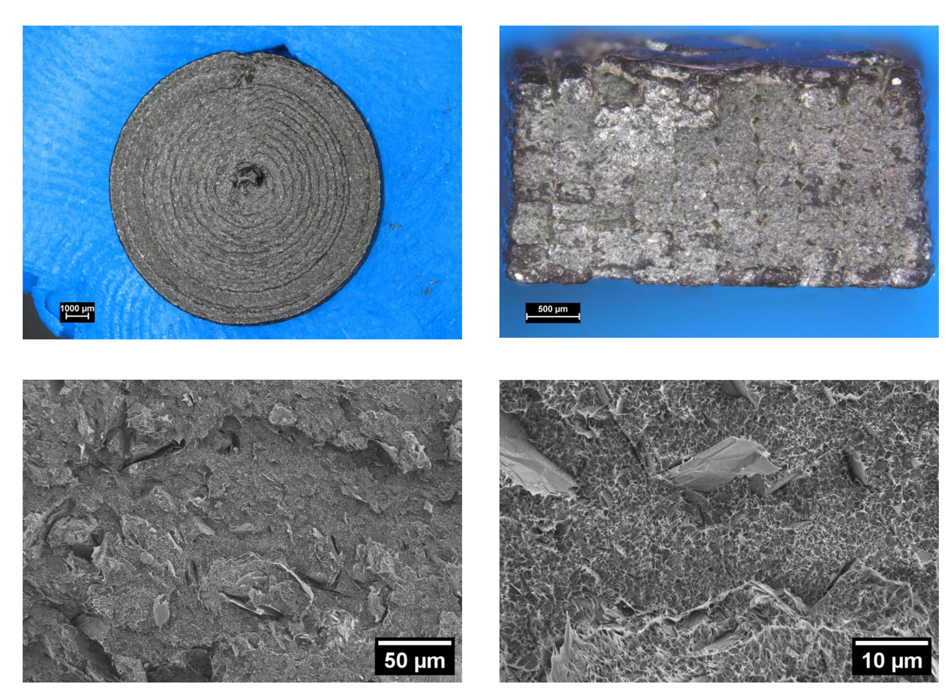


Mettler DSC5+
30–60 °C, 1 °C/min
Nitrogen flow 100 ml/min

SAMPLE	T_{m2} (°C)	ΔH_{m2} (J/g)
SA	58.6	**193.7**
PE-50SA/EG14	57.2	**61.9**

Melting enthalpy: 62 J/g

Good starting point, but the goal is usually **>100 J/g** (i.e. change PCM)

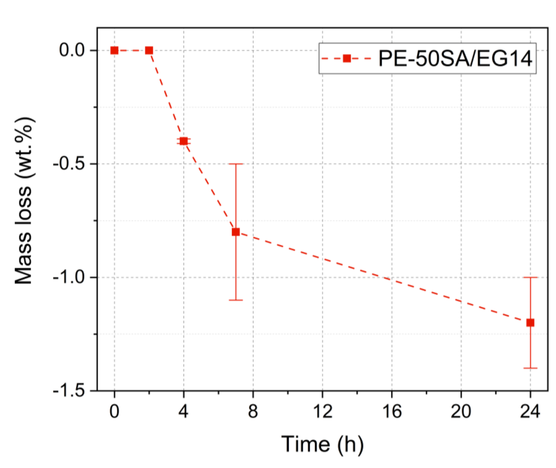


Problems:

- Regularity in the filament diameter
- Counterflow PCM in the cylinder

CONTAINED LEAKAGE

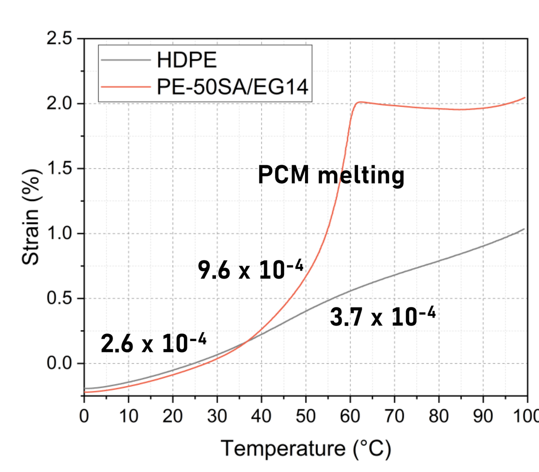
70 °C



Bulk density

Coefficient of Thermal Expansion (CTE):

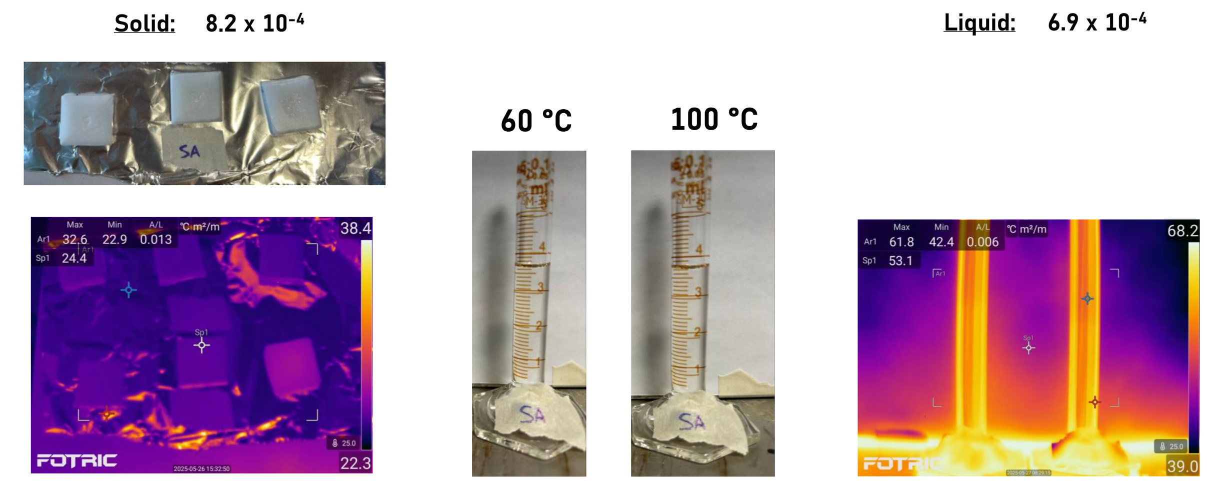
DMA measurements,
Tensile configuration
0–100 °C, 1 °C/min
preload 0.001 N



For the **PCM**:
volume measurements + IR thermography

Solid: 8.2 x 10⁻⁴

Liquid: 6.9 x 10⁻⁴

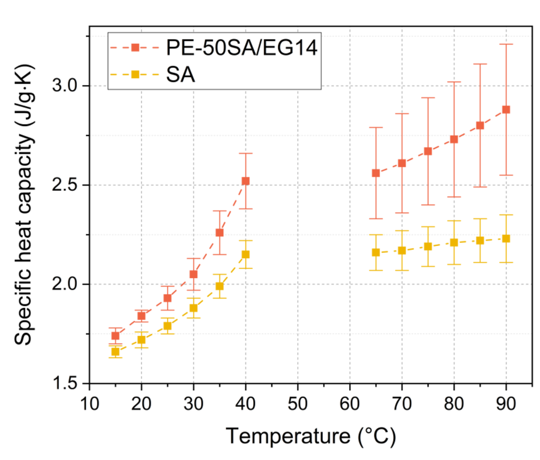


Thermophysical properties

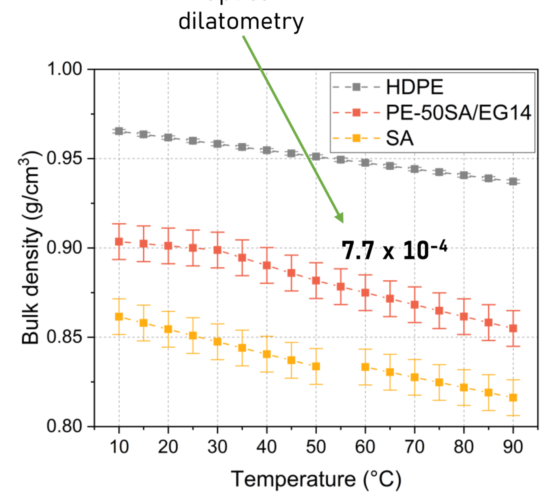
$$\lambda = \alpha \cdot \rho \cdot c_p$$

- λ : thermal conductivity $\left(\frac{W}{m \cdot K}\right)$
- α : thermal diffusivity $\left(\frac{mm^2}{s}\right)$
- ρ : bulk density $\left(\frac{g}{cm^3}\right)$
- c_p : specific heat capacity $\left(\frac{J}{g \cdot K}\right)$

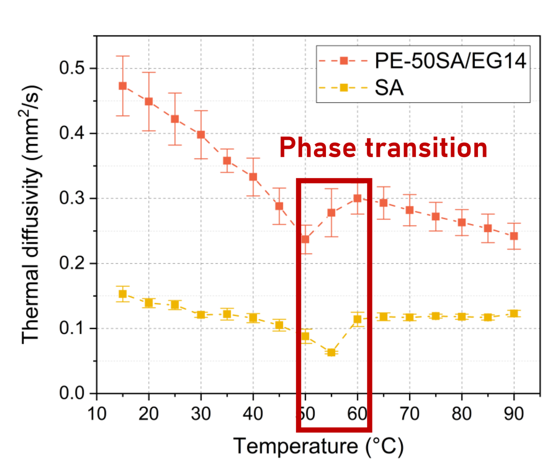
ASTM E1269 – 11 standard:
Mettler DSC5+: dyn 10 – 95 °C, **1°C/min**



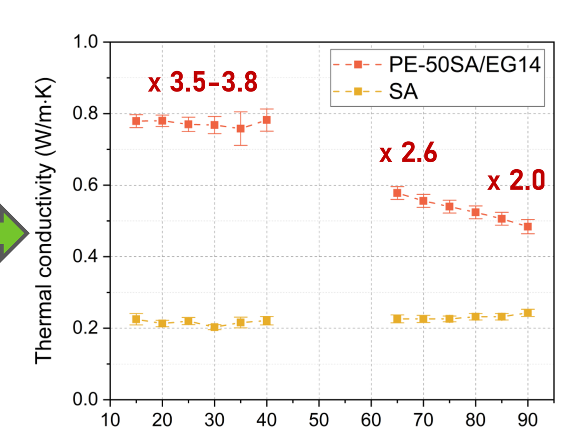
Optical dilatometry



Laser Flash Analyser Neztsch LFA 467
D = 12.5 mm, t = 2.5 mm
3 shots, 3 specimens

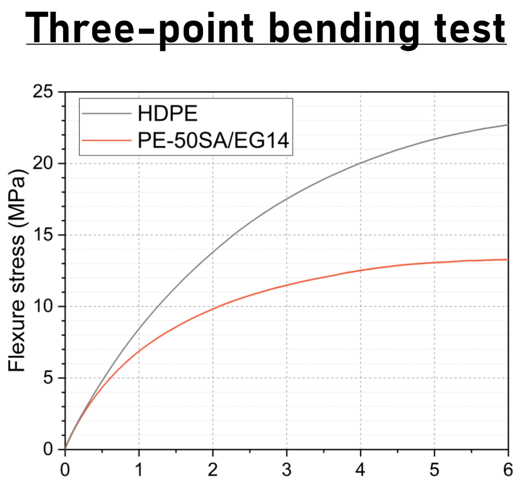


Thermal Conductivity enhancement

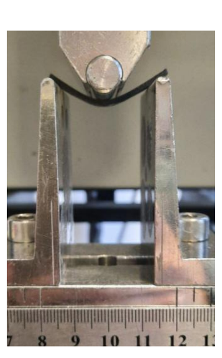


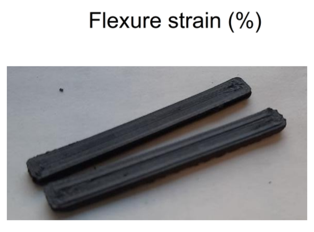
Three-point bending test

ASTM D790-17 standard



Instron 5969
Load cell 1 kN
0.853 mm/min
5 x 2 x 45 mm³

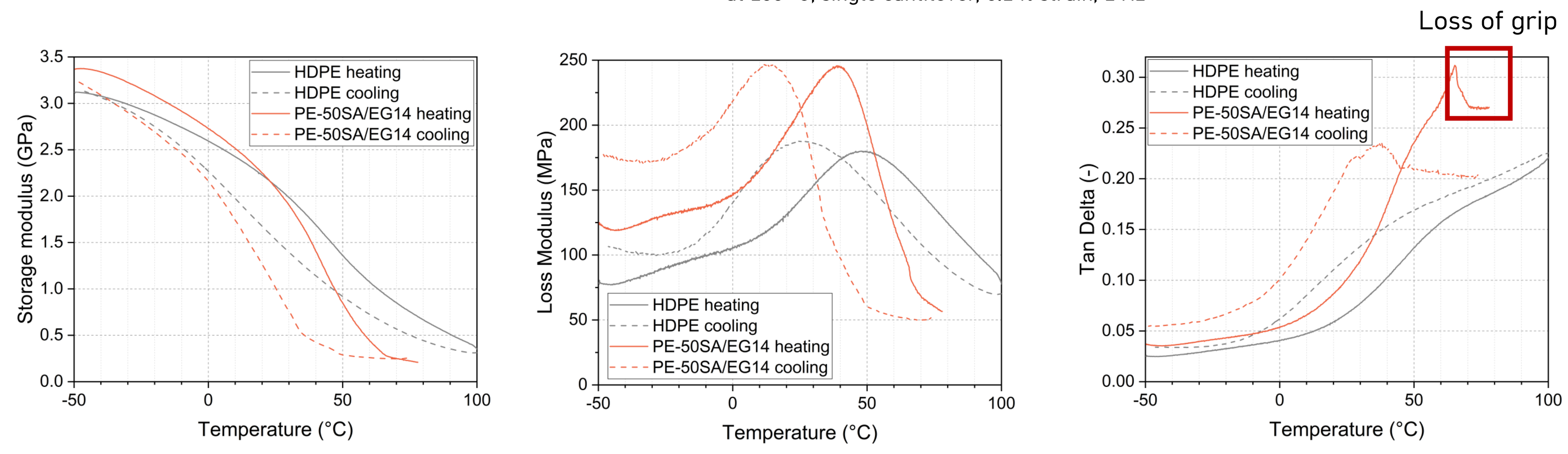




No broken specimens

Dynamic Mechanical Analysis (DMA)

Heating and cooling at 3 °C/min, 5 min isotherm at 100 °C, single cantilever, 0.1 % strain, 1 Hz



- Thermal inertia effects
- Superposition of HDPE β transition and PCM melting

Future perspectives

- Optimization of the composition
- Use of other organic PCMs (goal of 100 J/g)
- Optimize the process to obtain a more homogeneous filament

APPLICATION:

- Thermal management of electronic devices
- Complex geometries
- Design finned systems to enhance heat dissipation (PCM recrystallization)