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Examination of new FDM filaments for applications with large temperature variations

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Introduction & Aim

- 3D printing is nowadays also used for the production of customized objects, spare parts, etc. [1]
- Among the various 3D printing technologies, the fused deposition modeling (FDM) process is the most widely used due to its simplicity, the mostly nontoxic polymers, and the availability of inexpensive printers and materials [1]
- Printed parts often exhibit mechanical and thermal inadequacies
- Space applications such as microsatellites require stable mechanical properties under periodically strongly changing temperatures
- Microsatellites and similar space applications mostly need customized parts, making 3D printing suitable for such parts [2]

→ New FDM-printable polymers can help to make this technology usable for space applications

Materials and Methods

Here we investigate novel FDM filaments (GRAUTS GmbH) with and without fibrous fillers before and after cyclic temperature variations between – 40 °C and + 80 °C [3,4], similar to the situation of a microsatellite in the low Earth orbit (LEO):

Name	Material	Shore D	T_{glass}
HPP 52ShD	HPP	52	~ 50 °C
HPP 57 ShD	HPP	57	~ 50 °C
HPP + GF 1443	HPP with 15% glass fiber	84*	~ 55 °C
Mid GF 1470	PA with 15% glass fiber	78	~ 60 °C
Mid GF 1461	PA with 15% glass fiber	80*	~ 55 °C
PA + 15% CF	PA with 15% carbon fiber	75*	~ 60 °C
Flex S42	HPP	42	< -40 °C

Printing parameters:

Name	Nozzle temperature/°C	Bed temperature/°C	Speed/(mm/s)
HPP 52ShD	230	60	40
HPP 57 ShD	230	60	40
HPP + GF 1443	230	60	50
Mid GF 1470	245	85	50
Mid GF 1461	245	85	50
PA + 15% CF	260	90	50
Flex S42	230	60	35

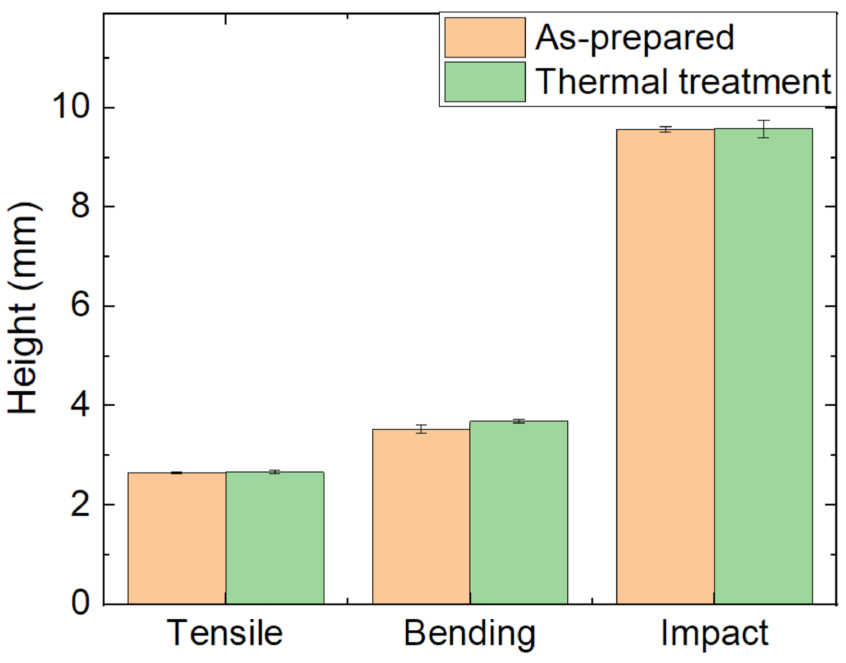
Sample dimensions:
- 3 mm x 10 mm x 75 mm (tensile tests, DIN EN ISO 6892-1)
- 10 mm x 10 mm x 55 mm (notch impact test)
- 4 mm x 10 mm x 100 mm (3-point bending, DIN EN ISO 178)

Heat treatment:
climate chamber CTC256 , 64 cycles between 80 °C and -40 °C

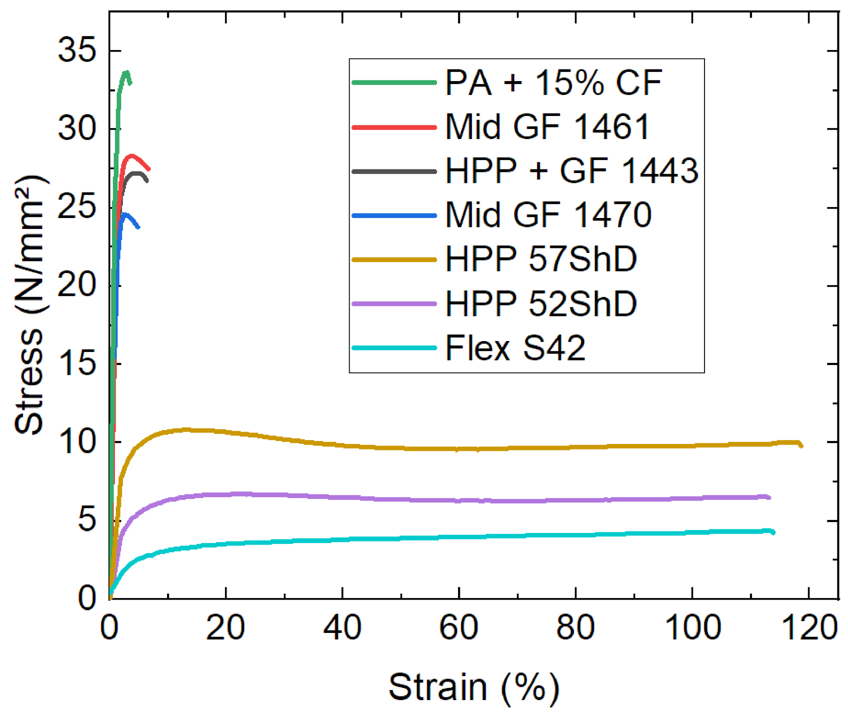
Characterization:
- Differential scanning calorimetry (DSC 3, Metler-Toledo)
- Digital microscope Camcolms 2 (Vellemann)
- Scanning electron microscope (SEM) Phenom ProX G3
- 3-point bending tests (Kern & Sohn GmbH) at 10 mm/(min
- Notched bar impact tests (pendulum tester, ZwickRoell)

Results

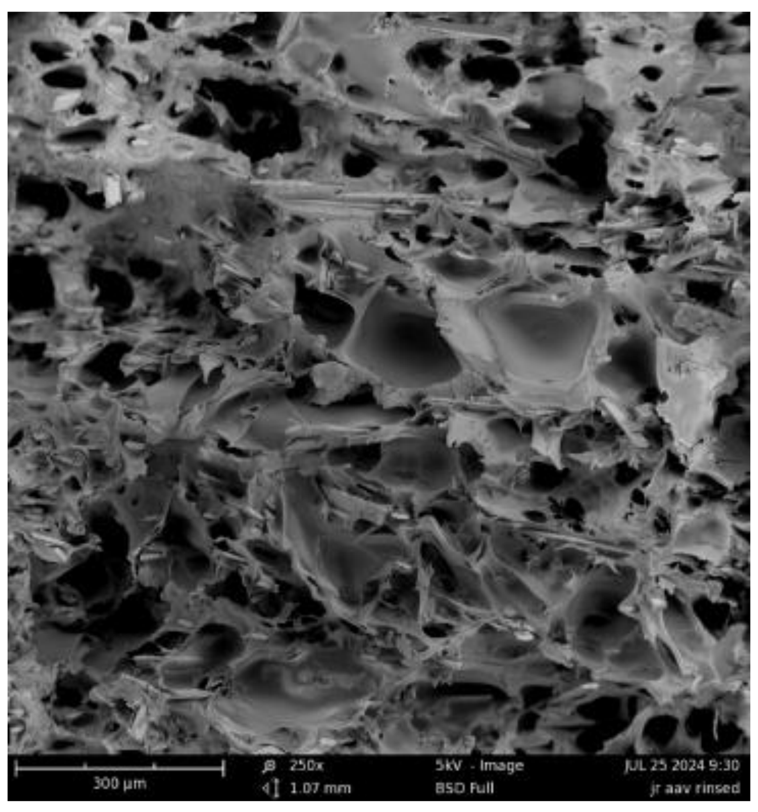
Dimensions:
- Heights generally ~ 0.4 mm too low → missing printing accuracy
- Lengths and widths printed correctly
- No changes after thermal treatment (same finding for lengths widths, respectively)



Tensile tests:
- Harder and more brittle samples (PA, Mid GF, HPP + GF) vs. elastic and more ductile ones
- Tensile strength after thermal treatment increased for Mid GF 1461, others unaltered
- Elongation at break reduced for HPP+GF1443



Fracture cross-sections:
- No fiber fracture visible
- Holes due to pulled-out fibers
- Matrix shows partial ductile failure + localized viscous stretching of the matrix between the fibers



Bending / impact tests:
- Maximum force increased
- Impact energy often reduced

Literature

[1] Noorani, R. Rapid prototyping: principles and applications. New Jersey: John Wiley & Sons, 2005
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[4] Storck, J. L.; Ehrmann, G.; Güth, U.; Uthoff, J.; Homburg, S. V.; Blachowicz, T.; Ehrmann, A. Investigation of Low-Cost FDM-Printed Polymers for Elevated-Temperature Applications. Polymers 2022, 14, 2826

Conclusion

- Thermal treatment did not change the sample dimensions.
- Tensile strength remained nearly unaltered.
- Maximum force in bending tests was increased.
- Notched bar tests showed a reduction of the higher impact energies, while lower values remained virtually unaltered.

→ Especially brittle and Flex42 filaments suitable for applications with strongly varying temperatures
→ More research needed to improve printing quality

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