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MECHANICAL CHARACTERIZATION OF 3D-PRINTED SAMPLES

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1. Introduction

Additive manufacturing is gaining greater and greater popularity in the last few years [1], with fused deposition modelling (FDM) becoming an accessible tool for rapid prototyping with plastic-based materials. Due to its building process, the mechanical properties of 3D-printed objects are substantially different from those of the same object of the same material, but obtained by a different manufacturing process, i.e. injection molding [2]. In this paper, we investigate the results of tensile tests on 3D-printed specimens made of various plastic and composite materials.

2. Methods

ASTM D1822 standard specimens were used in tensile tests, Fig.1. The specimens were built in two different orientations: flat on the buildplate, and standing on one side, as shown in Fig. 2.

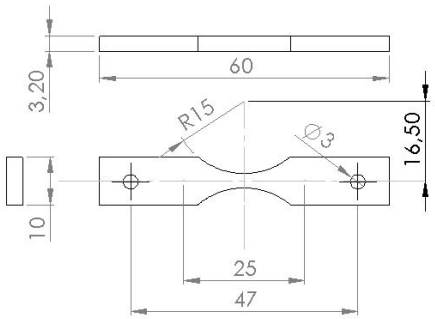

Fig. 1. Geometry of the ASTM D1822 specimen

The specimens were printed by a 3D Builder Premium™ machine in three different materials: a PLA (Poly Lactic Acid) plastic filament by Builder™, a composite material, Bronzefill by ColorFabb™, made of a bronze powder in a PLA matrix, and the thermoplastic elastomer Innoflex 45 by Innofil™. The main printing parameters are given in Tab. 1.

All specimens were tested in tension using a test-rig originally designed to apply small loads during micro-CT acquisitions [3], equipped with a load cell and an encoder coupled with a computer interface, which read and saved these values at regular time intervals.

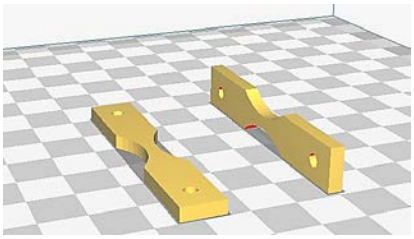

Fig. 2. Flat-built (left) and side-built (right) specimen.

The stress-strain curve of each specimen was obtained. Young's modulus, maximum stress and strain at maximum stress were computed as well.

	PLA	Bronze fill	Inno-flex 45
# flat-built samples	20	6	3
# side-built samples	3	1	2
Print temperature, °C	210	210	220
Print speed, mm/s	60	50	40
Layer height, mm	0.2	0.2	0.2
Wall thickness, mm	0.8	0.8	0.8
Infill density	100%	100%	100%
Infill pattern	Grid	Grid	Grid

Tab. 1. Samples and print parameters.

3. Results

The specimens exhibit different behaviors depending not only on the material but also on the building orientation, as shown in Figg. 3-6.

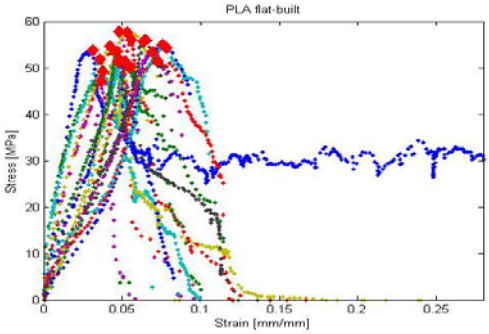

Fig. 3. Stress–Strain curves of PLA flat-built samples.

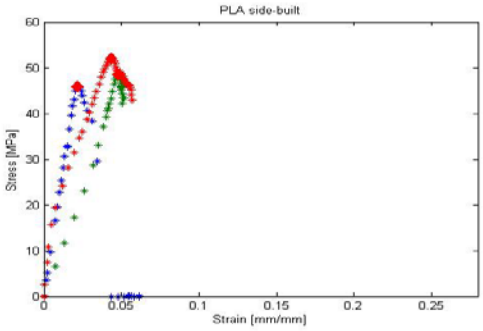

Fig. 4. Stress–Strain curves for PLA side-built samples.

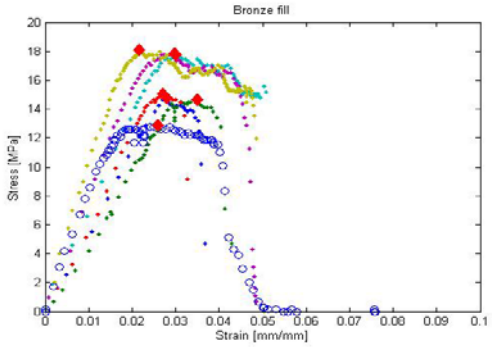

Fig. 5. Stress–Strain curves for flat-built (♦) and side-built (o) PLA bronze fill samples.

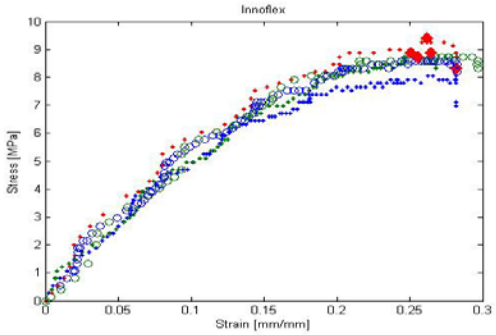

Fig. 6. Stress–Strain curves flat-built (♦) and side-built (o) Innoflex 45 specimens.

Tab. 2 summarizes the results (average and standard deviation) of the measured parameters.

The stress-strain curves are often far from linear, which is an issue when defining Young's modulus [4]. In this work, Young's modulus was obtained as the linear regression in the elastic part of the curve that gave the minimum RMS error.

It should be noted that, on average, pure PLA exhibits a greater Young's modulus than the other materials and pure PLA also shows the greatest maximum stress, notwithstanding the relatively high dispersion of these results, which is typical of polymeric materials [5].

	PLA flat-built	**PLA side-built**	**Bronze fill (all)**	**Inno-flex 45 (all)**
Maximum stress, MPa	**53.20** (2.70)	**48.8** (2.59)	**15.86** (1.88)	**8.84** (0.34)
Strain at max. stress, mm/mm	**0.053** (0.013)	**0.038** (0.012)	**0.028** (0.004)	**0.263** (0.011)
Young's modulus, MPa	**1610** (1132)	**2091** (916)	**705** (207)	**73** (27)

Tab. 2. Average and standard deviation of the measured parameters.

4. Remarks

- It should be noted that the speed at which a specimen is loaded affects the curve but cannot be exactly controlled since the test-rig is hand-driven. Upgrade to a motor-driven device has already been planned.
- The PLA Bronzefill composite material has definitely poorer mechanical properties than pure PLA. Since the metal particles are not fibers, they do not improve the material's resistance. We expect the opposite behavior on 3D-printed carbon-reinforced composites, which we plan to test.
- The Innoflex 45 elastomer specimens underwent large deformations with no specimen reaching the breaking point within the range of operation of the test-rig.

References

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[4] Roger Brown, Handbook of Polymer Testing, UK, 2002.