A novel framework for design-property decision-making in polymer lattices when controlling for printed mass

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The overall project goal is to develop a lattice software toolkit to lower the barrier of entry by enabling the control of output variables, such as mass and modulus, to more broadly incorporate additively manufactured (AM) polymer lattices into sporting equipment [1]. The objectives of this study are to: (i) define a novel framework to evaluate lattices using selective laser sintering (SLS) Digital Foam™ materials, (ii) investigate the printability and compression performance of lattice designs used for sporting equipment, and (iii) understand the design-property relationships when controlling for printed mass (i.e., digital lattice volume).

Materials and Methods

50x50x30mm specimens were designed in nTopology software v.2.30.3 using strut-based and sheet-based lattices: voronoi, kelvin, body centered cubic (BCC), and gyroid. Independent variables of digital lattice volume (12, 15, 18, and 21 ±1 cm^3; volume of material making up the lattice) and strut/sheet thickness (1.0, 1.3, 1.6, and 1.9 mm) were set, as shown in Table 1, while cell size (5-15 mm) was calculated to fulfill the corresponding target mass groups A-D. Elastomer TPE300 and rigid PA11 materials were printed on EOS printers (N_{Total}=92, *n=3* per design). Specimen mass and dimensional accuracy were measured after depowdering. Compression testing was conducted following a modified ASTM D3574-Test C procedure [2]. Multiple one-way analysis of variance (ANOVA) were performed using Minitab 17.

Table 1: Inputs and TPE300 Mass (*n=3*) for A, B (Group C and D, and PA11 Mass not shown)

Mass Group	Strut/Sheet Thickness (mm)	Cell Size (mm)	Lattice Type	Digital Lattice Volume (cm^3)	TPE300 Mass (g)
A	1.0	5.5	BCC	11.61	14.0 ±0.5
		6.0	Kelvin	11.91	13.6 ±0.3
		6.0	Voronoi	12.16	14.6 ±0.5
		11.5	Gyroid	12.61	13.9 ±0.6
B	1.3	6.0	BCC	14.35	17.0 ±0.3
		6.5	Kelvin	15.74	19.5 ±0.7
		7.0	Voronoi	15.56	17.9 ±0.4
		12.0	Gyroid	15.42	18.6 ±0.3

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Results and Discussion

Printed mass was statistically different between mass groups A-D for TPE300 ($p<0.05$) and PA11 ($p<0.05$), which validated mass could be controlled across different materials and several lattice design inputs (lattice type-strut thicknesss-cell size). Further, design-property relationships were validated across multiple pre-set mass ranges which has not been previously reported in literature [3].

Compression testing results revealed that the properties of modulus, stress at 30% strain ($\sigma_{30\%}$), and energy capacity within a selected material could be tuned 3-7x for similar printed mass and strut/sheet thicknesses. As shown in Figure 1, gyroid and kelvin had a stiffer behavior when compared to voronoi and BCC, and rigid PA11 had stronger response of ~5-15x larger $\sigma_{30\%}$ compared to elastomeric TPE300.

Collectively, the study validated the design-print-test workflow of Digital Foam™ across multiple lattice designs. The results show engineers how compression properties of SLS lattices across soft and rigid materials can be engineered to meet sports equipment product requirements while maintaining mass targets. Compiling these critical lattice-property databases into a software toolkit will provide: (i) reduced effort by designers and engineers to replace foam via drop-in lattice solutions, (ii) increased sustainability by reduced physical prototype iterations, and (iii) broad industry technology advancement through wider adoption of SLS lattices across sporting disciplines and levels of play.

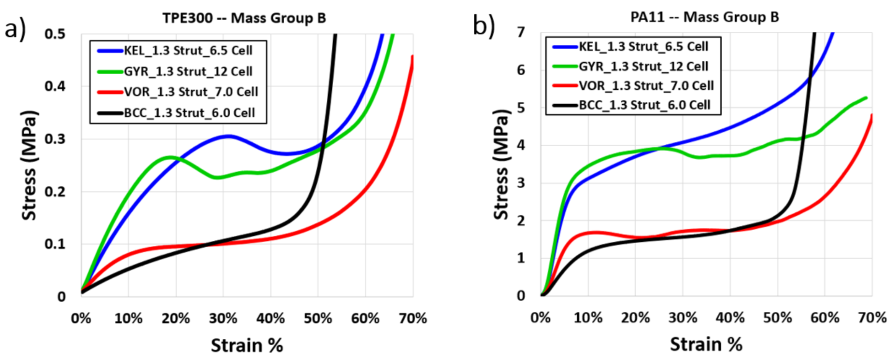

Fig. 1: Stress-strain curves across lattice types in Mass Group B for (a) TPE300 and (b) PA11

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2. ASTM D3574-17, 2017. ASTM International.
3. Rossiter JD, Johnson AA, and Bingham GA (2020) Assessing the Design and Compressive Performance of Material Extruded Lattices. 3D Printing and Additive Manufacturing, 7, 1, 19-27

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