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Data Article

Data on dielectric strength heterogeneity associated with printing orientation in additively manufactured polymer materials

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ABSTRACT

The following data describe the dielectric performance of additively manufactured polymer materials printed in various orientations for four common additive manufacturing techniques. Data are presented for selected commercial 3D printing materials fabricated using four common 3D printing techniques: Stereolithography (SLA), Fused Deposition Modeling (FDM), Selective Laser Sintering (SLS), and Polymer Jetting (PolyJet). Dielectric strengths are compiled for the listed materials, based on the ASTM D139 standard. This article provides data related to "Dielectric Strength Heterogeneity Associated with Printing Orientation in Additively Manufactured Polymer Materials" [1].

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Specifications Table

Subject area	*Materials Science*
More specific subject area	*Dielectric properties of 3D printed polymers*
Type of data	*Table data*
How data was acquired	*High voltage breakdown testing according to the ASTM D149 standard*
Data format	*Raw data*
Experimental factors	*Samples were preconditioned at 23°C and 50% relative humidity for 40 hours before dielectric strength testing*
Experimental features	*These experiments provide dielectric strength data from high voltage breakdown testing of samples printed in various orientations using four common additive manufacturing techniques*
Data source location	*Not Applicable*
Data accessibility	*All relevant data included in this article*
Related research article	Hoff et al. [1].

Value of the data

- These data compare dielectric strengths of several different additively manufactured materials printed in various orientations.
- The data highlight anisotropic behavior in additively manufactured materials through the inspection of dielectric properties. Other properties such as mechanical strength, optical properties, and surface properties could be similarly anisotropic.
- The data demonstrate the relationship between processing and performance that may be overlooked in industrial practices and may lead to suboptimal products.
- The data are useful for the design of high voltage insulators based on 3D printed polymers.

1. Data

Tabular data previously summarized in Ref. [1] are presented for dielectric strength testing of 3D printed polymers. Dielectric strength testing was performed according to the ASTM D139 standard [2]. Dielectric strength test samples were fabricated using four common 3D printing techniques: Stereolithography (SLA), Fused Deposition Modeling (FDM), Selective Laser Sintering (SLS), and Polymer Jetting (PolyJet) [3]. Data for SLA samples printed using the Watershed 11122 [4] and ProtoGen 18420 [5] polymers, with a layer resolution 0.051 mm, are provided in Tables 1 and 2, respectively. Data for FDM samples printed using the ABS-M30 [6] and ABS-M30i [7] polymers, with a layer resolution of 0.127 mm, are presented in Tables 3 and 4, respectively. Data for SLS samples printed using the DuraForm HST [8] (0.102 mm layer resolution) and Nylon EX [9] (0.152 mm layer resolution) polymers are presented in Tables 5 and 6, respectively. Data for PolyJet samples printed using the VeroBlue [10] and VeroAmber [10] polymers, with a layer resolution of 0.030 mm, are presented in Tables 7–9 (VeroBlue) and Tables 10–12 (VeroAmber).

2. Experimental design, materials and methods

Test sample coupons, fabricated as assemblies in a disposable shell, were printed in either two or three different orientations, as depicted in Fig. 1. For vertically-aligned samples, the surface of each sample face was aligned perpendicularly to the build platform and either perpendicular or parallel to the sweep direction of the print head, as shown in Fig. 1, corresponding to the “(V1)” and “(V2)”

Table 1
Dielectric strength data for SLA-printed Watershed 11122 samples.

Material (Orientation)	Thickness [in]	Thickness [mm]	Breakdown Voltage [kV]	Dielectric Strength [kV/mm]	Average [kV/mm]	Standard Deviation [kV/mm]
WaterShed 11122 (V)						
Trial 1	0.041	1.041	33.0	31.7		
	0.041	1.041	32.0	30.7		
	0.042	1.067	30.5	28.6		
	0.041	1.041	31.5	30.2		
	0.041	1.041	32.0	30.7	30.4	1.0
WaterShed 11122 (H)						
Trial 1	0.044	1.118	32.0	28.6		
	0.044	1.118	31.0	27.7		
	0.043	1.092	29.0	26.6		
	0.043	1.092	30.5	27.9		
	0.045	1.143	32.5	28.4	27.9	0.7

Table 2
Dielectric strength data for SLA-printed ProtoGen 18420 samples.

Material (Orientation)	Thickness [in]	Thickness [mm]	Breakdown Voltage [kV]	Dielectric Strength [kV/mm]	Average [kV/mm]	Standard Deviation [kV/mm]
ProtoGen 18420 (V)						
Trial 1	0.041	1.041	33.0	31.7		
	0.041	1.041	32.0	30.7		
	0.042	1.067	30.5	28.6		
	0.041	1.041	31.5	30.2		
	0.041	1.041	32.0	30.7	30.4	1.0
ProtoGen 18420 (H)						
Trial 1	0.039	0.991	27.0	27.3		
	0.043	1.092	26.0	23.8		
	0.037	0.940	26.0	27.7		
	0.043	1.092	26.0	23.8		
	0.044	1.118	28.0	25.1	25.5	1.7

designations, respectively. In cases where vertically-aligned samples are fabricated using printing methods in which layer deposition is performed without a print head or nozzle, such as SLS and SLA, it was not expected that there would be a difference in sample properties between vertical configurations (V1) and (V2); as such, these cases are designated only as "(V)." For horizontally-aligned samples, the surface of each sample face was oriented parallel to the build volume, as depicted in Fig. 1. Cases involving horizontally-aligned samples are given "(H)" designations (Table 11).

Upon completion of the printing process, any support materials associated with the printing process that were in the regions between test coupons or otherwise attached to the assembly were removed. As part of the standard manufacturer printing protocol, all SLA-printed parts were UV

Table 3
Dielectric strength data for FDM-printed ABS-M30 samples.

Material (Orientation)	Thickness [in]	Thickness [mm]	Breakdown Voltage [kV]	Dielectric Strength [kV/mm]	Average [kV/mm]	Standard Deviation [kV/mm]
ABS-M30 (V1)						
Trial 1	0.039	0.991	33.0	33.3		
	0.040	1.016	29.5	29.0		
	0.040	1.016	32.5	32.0		
	0.040	1.016	31.0	30.5		
	0.040	1.016	33.5	33.0	31.6	1.6
ABS-M30 (V2)						
Trial 1	0.040	1.016	33.5	33.0		
	0.041	1.041	33.5	32.2		
	0.040	1.016	32.0	31.5		
	0.039	0.991	31.5	31.8		
	0.040	1.016	32.5	32.0	32.1	0.5
ABS-M30 (H)						
Trial 1	0.041	1.041	7.0	6.7		
	0.040	1.016	7.5	7.4		
	0.042	1.067	8.5	8.0		
	0.040	1.016	10.0	9.8		
	0.041	1.041	10.0	9.6	8.3	1.2

Table 4
Dielectric strength data for FDM-printed ABS-M30i samples.

Material Name	Thickness [in]	Thickness [mm]	Breakdown Voltage [kV]	Dielectric Strength [kV/mm]	Average [kV/mm]	Standard Deviation [kV/mm]
ABS-M30i (V1)						
Trial 1	0.040	1.016	31.5	31.0		
	0.040	1.016	31.0	30.5		
	0.040	1.016	31.5	31.0		
	0.039	0.991	30.5	30.8		
	0.040	1.016	31.0	30.5	30.8	0.2
ABS-M30i (V2)						
Trial 1	0.040	1.016	31.5	31.0		
	0.040	1.016	31.0	30.5		
	0.040	1.016	32.0	31.5		
	0.040	1.016	31.5	31.0		
	0.040	1.016	32.5	32.0	31.2	0.5
ABS-M30i (H)						
Trial 1	0.040	1.016	14.5	14.3		
	0.039	0.991	26.0	26.2		
	0.039	0.991	28.5	28.8		
	0.040	1.016	24.5	24.1		
	0.040	1.016	25.0	24.6	23.6	4.9

Table 5
Dielectric strength data for SLS-printed Duraform HST samples.

Material (Orientation)	Thickness [in]	Thickness [mm]	Breakdown Voltage [kV]	Dielectric Strength [kV/mm]	Average [kV/mm]	Standard Deviation [kV/mm]
DuraForm HST (V)						
Trial 1	0.041	1.041	12.5	12.0		
	0.042	1.067	13.0	12.2		
	0.039	0.991	12.0	12.1		
	0.041	1.041	13.5	13.0		
	0.042	1.067	12.0	11.2	12.1	0.5
DuraForm HST (H)						
Trial 1	0.040	1.016	18.0	17.7		
	0.039	0.991	19.0	19.2		
	0.039	0.991	17.5	17.7		
	0.039	0.991	18.5	18.7		
	0.039	0.991	15.0	15.1	17.7	1.4

Table 6
Dielectric strength data for SLS-printed Nylon EX samples.

Material (Orientation)	Thickness [in]	Thickness [mm]	Breakdown Voltage [kV]	Dielectric Strength [kV/mm]	Average [kV/mm]	Standard Deviation [kV/mm]
Nylon EX (V)						
Trial 1	0.040	1.016	25.5	25.1		
	0.040	1.016	26.0	25.6		
	0.041	1.041	24.5	23.5		
	0.039	0.991	23.0	23.2		
	0.040	1.016	24.5	24.1	24.3	0.9
Nylon EX (H)						
Trial 1	0.040	1.016	30.0	29.5		
	0.039	0.991	25.5	25.7		
	0.039	0.991	30.5	30.8		
	0.039	0.991	30.0	30.3		
	0.038	0.965	28.0	29.0	29.1	1.8

post-cured for one hour. Post cure procedures are potentially available for other printing methods; however, as they are not standard protocol, they were not performed for this study.

In preparation for high voltage testing, each of the sample assemblies was separated into five sample coupons (101.6 mm $\times$ 101.6 mm $\times$ 1.0 mm) and a disposable protective shell, as shown in Fig. 2. After separation, each sample coupon was cleaned via gentle abrasion while immersed in Liquinox (*aq.*, 1% solution). Following six rinses with deionized water, sample coupons were placed between sheets of lint-free tissue and allowed to air dry at ambient temperature. Dry coupons were stored between clean sheets of lint-free tissue in a desiccated environment for transportation to the dielectric strength testing laboratory.

Table 7
Dielectric strength data for PolyJet-printed VeroBlue (V1) samples.

Material (Orientation)	Thickness [in]	Thickness [mm]	Breakdown Voltage [kV]	Dielectric Strength [kV/mm]	Average [kV/mm]	Standard Deviation [kV/mm]
VeroBlue (V1)						
Trial 1	0.032	0.813	7.5	9.2		
	0.030	0.762	9.5	12.5		
	0.030	0.762	15.0	19.7		
	0.028	0.711	11.0	15.5		
	0.028	0.711	21.5	30.2	17.4	7.3
Trial 2	0.041	1.041	10.0	9.6		
	0.041	1.041	10.0	9.6		
	0.041	1.041	10.0	9.6		
	0.041	1.041	18.0	17.3		
	0.041	1.041	17.0	16.3	12.5	3.5
Trial 3	0.041	1.041	14.0	13.4		
	0.040	1.016	10.0	9.8		
	0.042	1.067	15.0	14.1		
	0.042	1.067	12.0	11.2		
	0.041	1.041	19.5	18.7	13.5	3.0
Trial 4	0.033	0.838	16.5	19.7		
	0.031	0.787	14.5	18.4		
	0.033	0.838	14.0	16.7		
	0.032	0.813	17.4	21.4		
	0.033	0.838	11.4	13.6	18.0	2.7
Trial 5	0.031	0.787	8.5	10.8		
	0.032	0.813	10.7	13.2		
	0.031	0.787	12.8	16.3		
	0.032	0.813	11.8	14.5		
	0.030	0.762	13.8	18.1	14.6	2.5

Just prior to testing, the sample coupons were pre-conditioned for 40 hours at 23 °C and 50% relative humidity. All coupons were tested per ASTM D149-09 (2013), Paragraph 12.2.1, Method A (short time test) [2] using 2.54 cm diameter stainless steel electrodes (ASTM “Type 2” electrodes) in a transformer oil bath. A voltage ramp rate of 500 VAC, RMS (60 Hz)/second was used. Ambient room conditions during testing were approximately 23 °C and 50% relative humidity.

Table 8
Dielectric strength data for PolyJet-printed VeroBlue (V2) samples.

Material (Orientation)	Thickness [in]	Thickness [mm]	Breakdown Voltage [kV]	Dielectric Strength [kV/mm]	Average [kV/mm]	Standard Deviation [kV/mm]
VeroBlue (V2)						
Trial 1	0.037	0.940	25.0	26.6		
	0.036	0.914	27.5	30.1		
	0.034	0.864	26.5	30.7		
	0.037	0.940	26.5	28.2		
	0.035	0.889	29.0	32.6	29.6	2.1
Trial 2	0.035	0.889	28.0	31.5		
	0.034	0.864	28.0	32.4		
	0.035	0.889	29.0	32.6		
	0.036	0.914	25.0	27.3		
	0.036	0.914	28.0	30.6	30.9	1.9
Trial 3	0.036	0.914	29.0	31.7		
	0.036	0.914	29.0	31.7		
	0.034	0.864	25.0	28.9		
	0.035	0.889	27.0	30.4		
	0.034	0.864	28.0	32.4	31.0	1.2

Table 9
Dielectric strength data for PolyJet-printed VeroBlue (H) samples.

Material (Orientation)	Thickness [in]	Thickness [mm]	Breakdown Voltage [kV]	Dielectric Strength [kV/mm]	Average [kV/mm]	Standard Deviation [kV/mm]
VeroBlue (H)						
Trial 1	0.038	0.965	29.5	30.6		
	0.039	0.991	31.0	31.3		
	0.039	0.991	30.0	30.3		
	0.039	0.991	30.5	30.8		
	0.040	1.016	31.5	31.0	30.8	0.3
Trial 2	0.039	0.991	30.0	30.3		
	0.039	0.991	32.0	32.3		
	0.040	1.016	29.0	28.5		
	0.039	0.991	31.0	31.3		
	0.040	1.016	32.0	31.5	30.8	1.3
Trial 3	0.039	0.991	32.0	32.3		
	0.038	0.965	31.0	32.1		
	0.040	1.016	32.0	31.5		
	0.039	0.991	31.0	31.3		
	0.039	0.991	33.0	33.3	32.1	0.7

Table 10
Dielectric strength data for PolyJet-printed VeroAmber (V1) samples.

Material (Orientation)	Thickness [in]	Thickness [mm]	Breakdown Voltage [kV]	Dielectric Strength [kV/mm]	Average [kV/mm]	Standard Deviation [kV/mm]
VeroAmber (V1)						
Trial 1	0.040	1.016	9.0	8.9		
	0.039	0.991	7.0	7.1		
	0.042	1.067	8.0	7.5		
	0.045	1.143	4.0	3.5		
	0.041	1.041	5.0	4.8	6.3	1.9
Trial 2	0.038	0.965	8.5	8.8		
	0.044	1.118	6.0	5.4		
	0.040	1.016	4.5	4.4		
	0.040	1.016	6.0	5.9		
	0.039	0.991	9.0	9.1	6.7	1.9
Trial 3	0.031	0.787	13.0	16.5		
	0.032	0.813	5.0	6.2		
	0.030	0.762	11.0	14.4		
	0.030	0.762	15.6	20.5		
	0.030	0.762	5.5	7.2	13.0	5.5
Trial 4	0.031	0.787	10.0	12.7		
	0.030	0.762	11.2	14.7		
	0.031	0.787	9.8	12.4		
	0.032	0.813	7.7	9.5		
	0.030	0.762	7.5	9.8	11.8	1.9

Table 11
Dielectric strength data for PolyJet-printed VeroAmber (V2) samples.

Material (Orientation)	Thickness [in]	Thickness [mm]	Breakdown Voltage [kV]	Dielectric Strength [kV/mm]	Average [kV/mm]	Standard Deviation [kV/mm]
VeroAmber (V2)						
Trial 1	0.042	1.067	33.0	30.9		
	0.037	0.940	27.0	28.7		
	0.038	0.965	30.5	31.6		
	0.042	1.067	30.5	28.6		
	0.039	0.991	33.0	33.3	30.6	1.8
Trial 2	0.034	0.864	28.0	32.4		
	0.035	0.889	29.0	32.6		
	0.033	0.838	27.0	32.2		
	0.034	0.864	29.0	33.6		
	0.034	0.864	30.0	34.7	33.1	0.9
Trial 3	0.036	0.914	28.0	30.6		
	0.035	0.889	30.0	33.7		
	0.037	0.940	32.0	34.0		
	0.035	0.889	31.0	34.9		
	0.034	0.864	29.0	33.6	33.4	1.4

Table 12
Dielectric strength data for PolyJet-printed VeroAmber (H) samples.

Material (Orientation)	Thickness [in]	Thickness [mm]	Breakdown Voltage [kV]	Dielectric Strength [kV/mm]	Average [kV/mm]	Standard Deviation [kV/mm]
VeroAmberH						
Trial 1	0.039	0.991	29.5	29.8		
	0.039	0.991	30.0	30.3		
	0.039	0.991	30.5	30.8		
	0.040	1.016	31.5	31.0		
	0.039	0.991	31.0	31.3	30.6	0.5
Trial 2	0.038	0.965	31.0	32.1		
	0.039	0.991	29.0	29.3		
	0.039	0.991	33.0	33.3		
	0.040	1.016	31.0	30.5		
	0.038	0.965	31.0	32.1	31.5	1.4
Trial 3	0.039	0.991	32.0	32.3		
	0.039	0.991	33.0	33.3		
	0.039	0.991	32.0	32.3		
	0.040	1.016	32.0	31.5		
	0.040	1.016	31.0	30.5	32.0	0.9

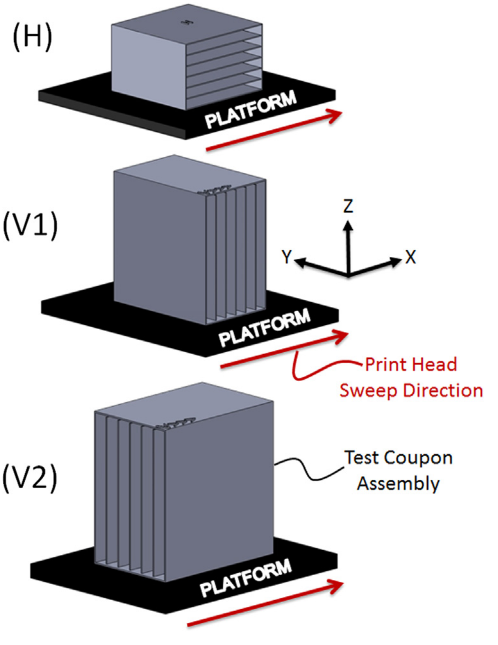

Fig. 1. Depictions of sample coupon and shell configurations used in the present study. For printing methods having a well-defined print head sweep direction, such as PolyJet, the sweep direction is indicated by an arrow next to the representative build platforms shown in the figure. Assigning the print head sweep direction to lie parallel to the X-axis follows the convention specified by Ref. [1].

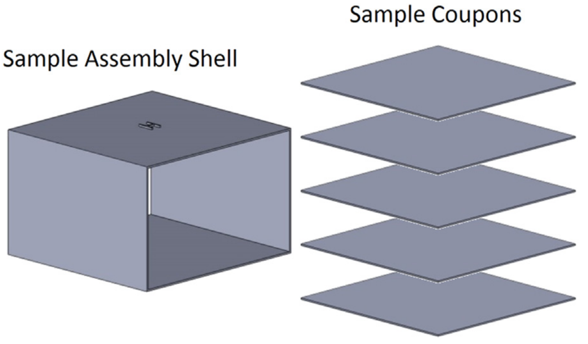

Fig. 2. Schematic representation of the sample assembly shell and sample coupons.

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Appendix A. Supporting information

Supplementary data associated with this article can be found in the online version at https://doi.org/10.1016/j.dib.2018.07.070.

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