Influence of 3D Printing on Safety-Critical Performance Properties

Ninth Triennial International Aircraft Fire and Cabin Safety Research Conference

October 30, 2019

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UL LLC

Material evaluation

Performance of Material in Finished Product

Performance of Material Alone

UL Plastics Recognition

- Avoids redundant testing for common properties (same material tested for each specific application)
- Identification of polymer properties
- Direct material comparison
- Material substitution capabilities

QMFZ2 Component - Plastics E123456

Plastics Company, Ltd.

1285 Walt Whitman Road, Melville, NY 11747 USA

ABC123

Polyamide 66 (PA66), furnished as pellets

Color	Min Thk (mm)	Flame Class	HWI	HAI	RTI Elec	RTI Imp	RTI Str
ALL	0.40	HB	-	-	65	65	65
	0.71	V-2	-	-	125	80	80
	1.5	V-2	3	0	125	80	85
	3.0	V-2	2	0	125	80	90

Comparative Tracking Index (CTI): **0**
Dimensional Stability (%): **1.0**
High-Voltage Arc Tracking Rate (HVTR): **0**
High Volt, Low Current Arc Resis (D495): **4**
Dielectric Strength (kV/mm): **15**
Volume Resistivity (10xohm-cm): **14**

UL94 small-scale test data does not pertain to building materials, furnishings and related contents. UL94 small-scale test data is intended solely for determining the flammability of plastic materials used in the components and parts of end-product devices and appliances, where the acceptability of the combination is determined by Underwriters Laboratories.

UV definitions:
(f1) = Suitable for outdoor use with respect to exposure to Ultraviolet Light, Water Exposure and Immersion in accordance with UL 746C.
(f2) = Subjected to one or more of the following tests: Ultraviolet Light, Water Exposure or Immersion in accordance with UL 746C, where the acceptability for outdoor use is to be determined by UL.

- Assurances based on Follow-Up Service and Continued Certification

Enables preselection of materials for faster product compliance evaluations

List of UL Standards (Product Categories) that Reference the UL 746C Standard

384 Product Categories/ Standards Reference UL 746C

UL 746C

Standard for Safety

As of 10/01/2017

Injection Molded vs. 3D Printed Parts

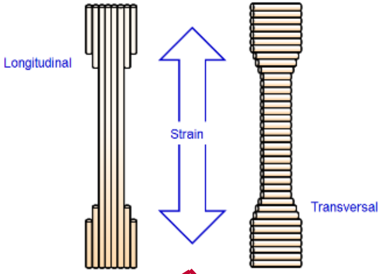
Injection Molded

3D Printed Parts

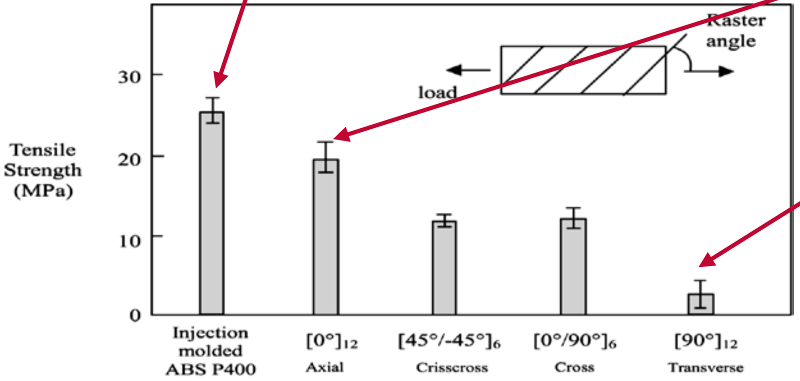
Influence of 3D Printing on Tensile Strength

Injection molded

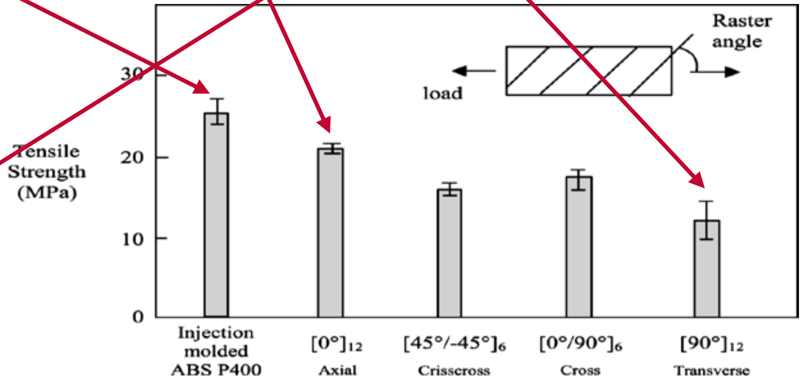
Cut from 3DP part



0” air gap



-0.003” air gap



Sung-Hoon Ahn et al., *Anisotropic material properties of fused deposition modeling ABS*, Rapid Prototyping, vol. 8 no. 4, p. 248 (2002)

UL 3D Printing Research Project

UL 3D Printing Research Project

Objective

Investigate the impact of 3D printing by Material Extrusion on printed polymer material properties and performance.

Safety critical performance properties

~$350k internally funded project

Better understanding of printer influences to guide product designers and UL engineers

- UL Listing of 3D printed components & end products
- UL Recognition of materials for 3D printing

Experiment Plan

frABS on $4k
desktop printer

PEI on $45k
industrial printer

DoE

Full factorial w/center DoE

- Build orientation
- Raster angle
- Air gap
- Layer thickness

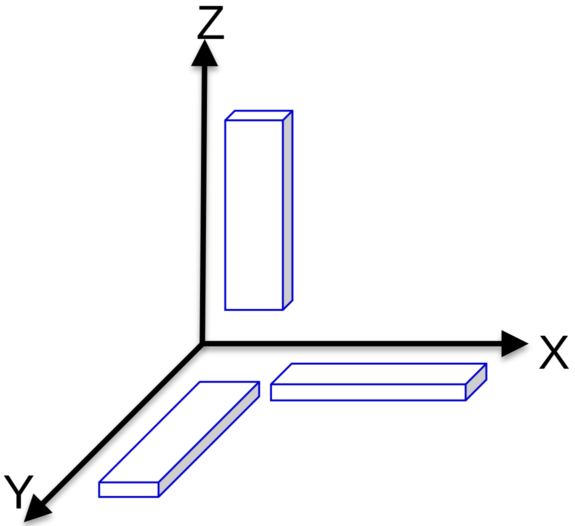
PLUS injection molded

UL 746 Tests

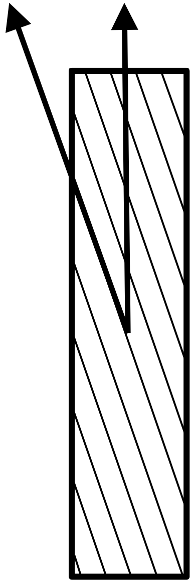
- Dielectric strength
- Volume resistivity
- CTI
- HAI
- HWI
- UL 94 flammability

Terminology

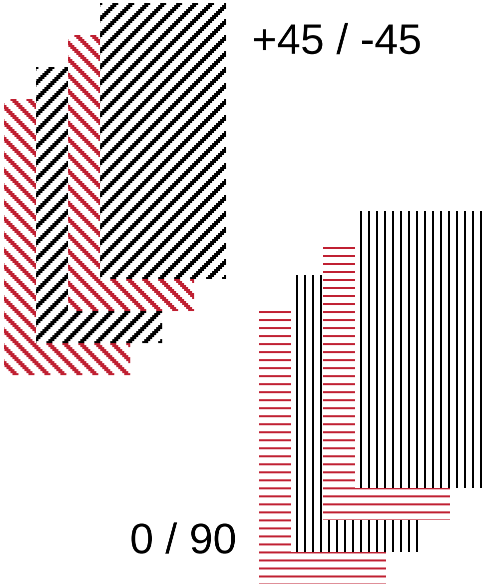
Build Orientation



Raster Angle, θ

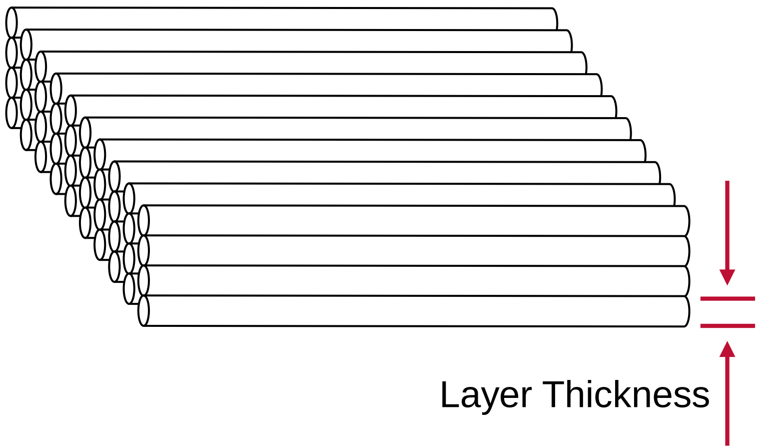


Build Strategy

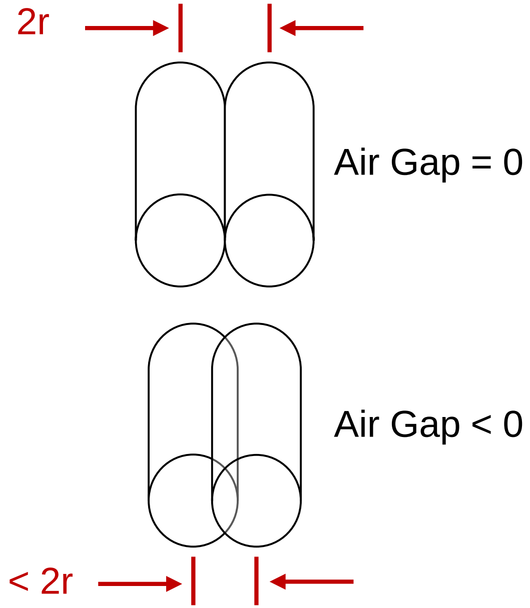


Terminology

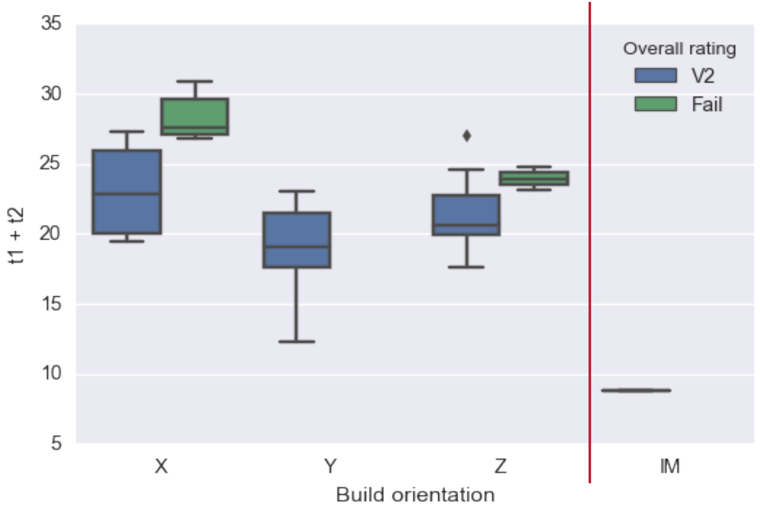
Layer Thickness

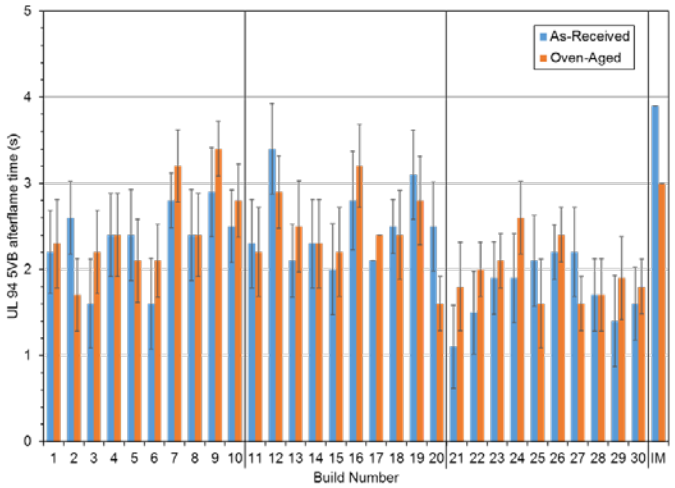


Air Gap



Flammability Results – UL 94 Vertical (and 5VB for PEI)





frABS

Typically V2

Build orientation significant factor

- X-direction: 5 of 9 failed
- Z-direction: 2 failed (thinnest layer + smallest air gap)
- Y-direction: 0 failed

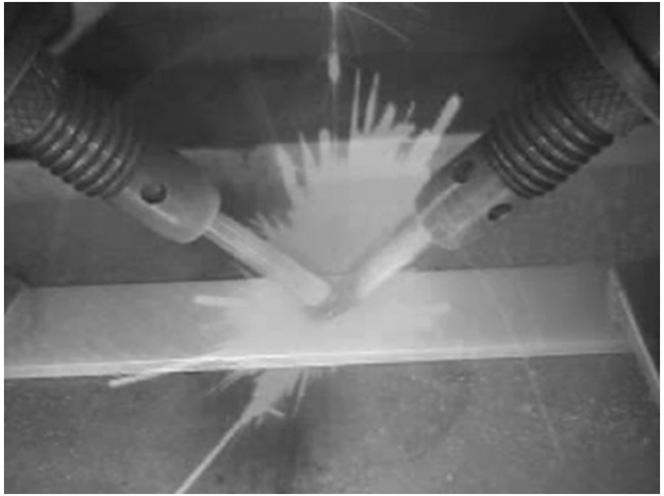
PEI

All 30 builds & Injection Molded: 5VB

Burn times typically 2 s or less

- Injection molded > 3D printed

High-current Arc Ignition (HAI) Results – UL 746A section 33



frABS

No samples ignited within maximum 150 arcs

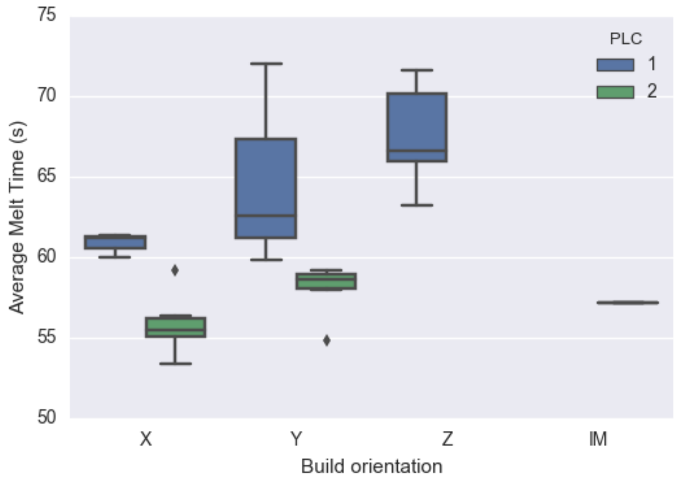
- PLC = 0

PEI

No ignition within maximum 150 arcs except:

- Two X-direction specimens at 137+ arcs
- One Z-direction specimen at 145 arcs
- PLC = 0

Hot Wire Index (HWI) Results – ASTM D3874



frABS

All specimens melted away

- PLC = 0 by standard

Build orientation significant factor

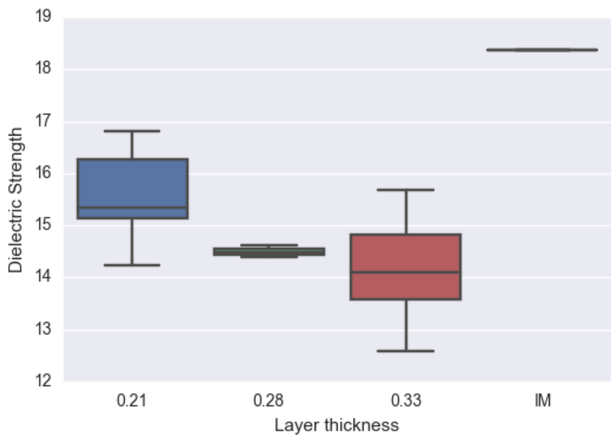
- X-, Y-direction: PLC = 2; some 1
- Z-direction: PLC = 1
- Injection molded: PLC = 2

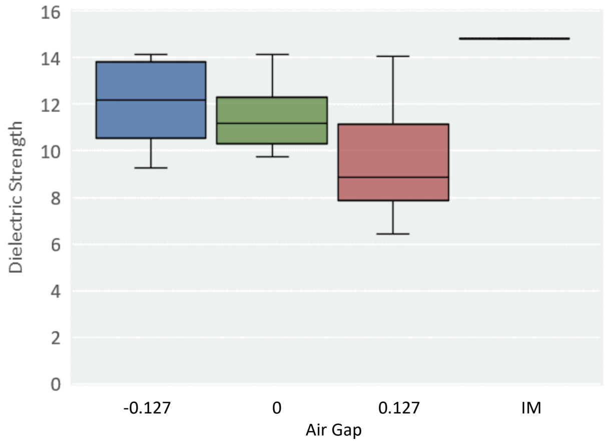
PEI

Build orientation significant factor

- X-direction: PLC = 0
- Y-direction: PLC = 0 & one PLC = 1
- Z-direction: 50:50 mix of PLC = 0 and 1
- Injection molded: PLC = 0

Dielectric Strength & Breakdown Voltage Results – IEC 60243





frABS

Dielectric breakdown occurred at the edge of the electrode

- 3D printed: AR > OA
- Injection molded: AR ≈ OA

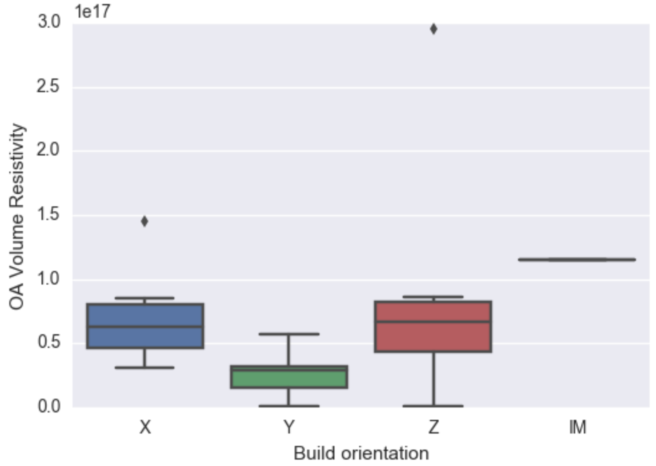
Layer Thickness and Raster Angle significant factors

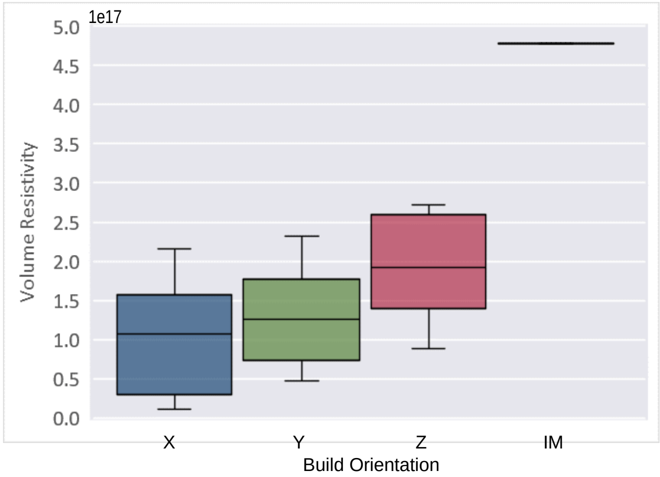
PEI

Dielectric breakdown occurred at the edge of the electrode

Air Gap significant factor

Volume Resistivity Results – IEC 60167





frABS

Results varied by 1.5 orders of magnitude

- 3D printed: AR > OA
- Injection molded: AR ≈ OA

Air Gap impacted aging

Build Orientation significant factor

PEI

Results varied by 2 orders of magnitude

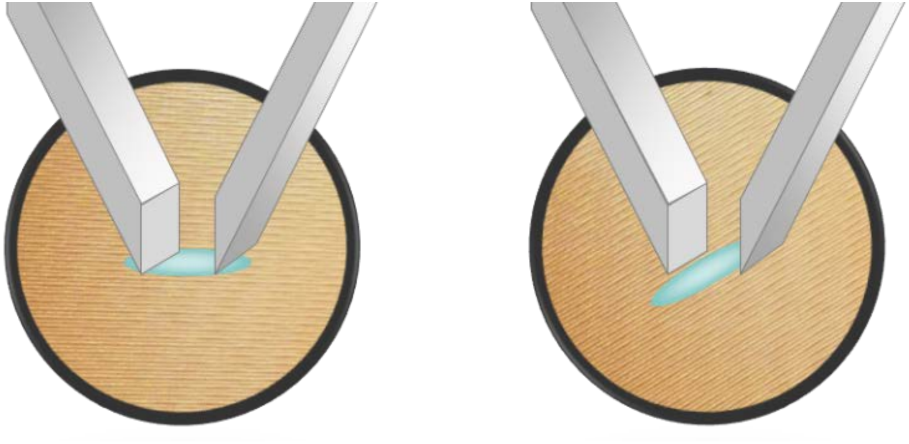
- 3D printed: AR > OA
- Injection molded: AR ≈ OA

Build Orientation significant factor

Comparative Tracking Index Testing (CTI) – IEC 60112

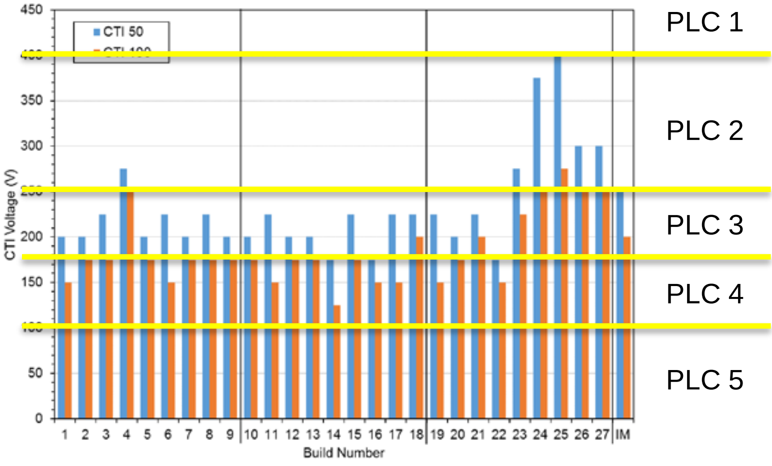
Section 5

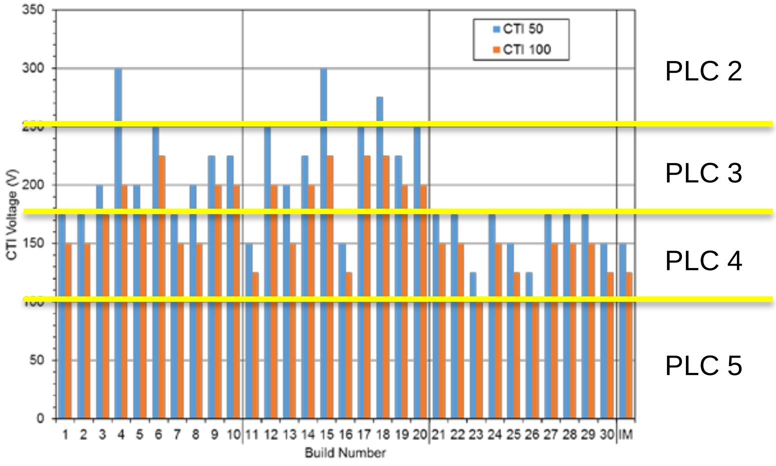
“Test specimens shall have nominally smooth and untextured surfaces which are free from surface imperfections such as scratches, blemishes, impurities, etc, unless otherwise stated in the product standard. If this is impossible, the results shall be reported together with a statement describing the surface of the specimen because certain characteristics on the surface of the specimen could add to the dispersion of the results.”



“…measurements shall be made in the direction of the feature and orthogonal to it.”

Comparative Tracking Index (CTI) Results – IEC 60112





frABS

PEI

Relative orientation of electrode to surface raster was important

- Higher CTI for orthogonal orientation on small Air Gap
- Higher CTI for parallel orientation on large Air Gap

Build Orientation significant factor

Some 3D print builds outperformed injection molded

UL 3D Printing Research Summary

ELECTRICAL, IGNITION, FLAMMABILITY PROPERTIES

- Injection molded dimensions are more consistent than 3D printed
- More consistent quality from industrial-grade printer than consumer-grade printer
- Build settings influence results
  Same material on same printer can yield critically different performance
- No 3D printed build outperformed injection molded (except CTI)
- Some test methods and practices may need to be updated for 3D printed specimens

- Research report available on ResearchGate (DOI: 10.13140/RG.2.2.26459.21287)

Applying Lessons Learned to End-Use Applications

Plastics Recognition Cards

UL iQ for Plastics

UL Yellow Card (QMFZ2/8) c UL US

IEC and ISO Test Methods

Test Name	Test Method	Units	Thickness Tested (mm)	Value
IEC Flammability	IEC 60695-11-10	Class	0.40	HB75 (ALL)
			0.71	V-2 (ALL)
Glow-Wire Flammability (GWFI)				
Glow-Wire Ignition (GWIT)				
IEC Comparative Tracking Index				
IEC Ball Pressure				
ISO Heat Deflection (1.80 MPa)				
ISO Tensile Strength				
ISO Flexural Strength				
ISO Tensile Impact				
ISO Izod Impact				
ISO Charpy Impact				

QMFZ2 Component - Plastics E123456

Plastics Company, Ltd.

1285 Walt Whitman Road, Melville, NY 11747 USA

ABC123

Polyamide 66 (PA66), furnished as pellets

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	0.71	V-2	-	-	125	80	80
	1.5	V-2	3	0	125	80	85
	3.0	V-2	2	0	125	80	90

Comparative Tracking Index (CTI): 0
High-Voltage Arc Tracking Rate (HVTR): 0
Dielectric Strength (kV/mm): 15
Dimensional Stability (%): 1.0
High Volt, Low Current Arc Resis (D495): 4
Volume Resistivity (10xohm-cm): 14

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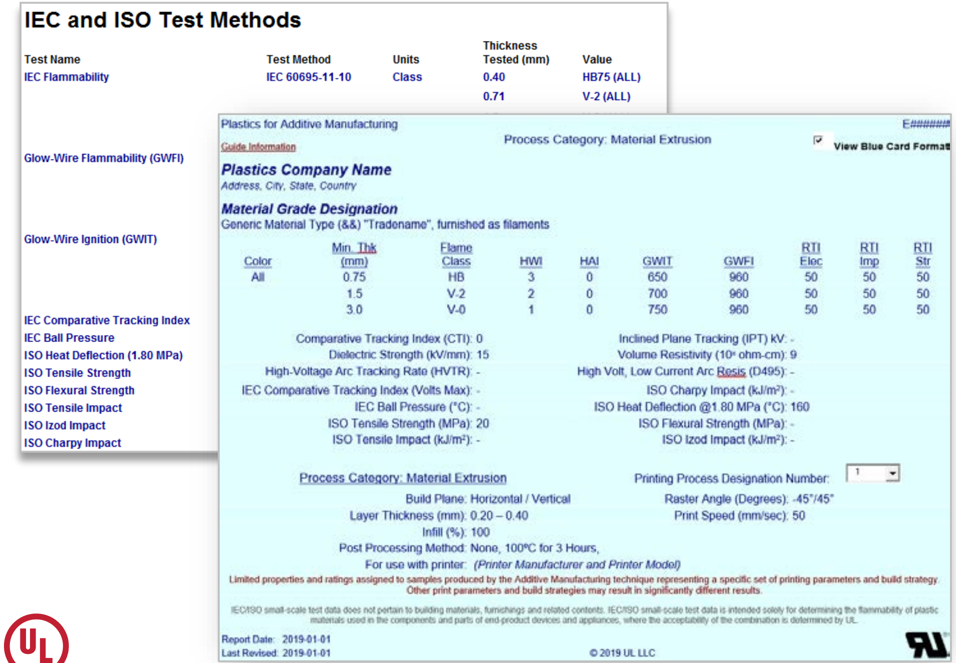
Traditional Processing

- Extrusion
- Injection molding
- Compression molding
- Blow molding
- Rotational molding
- Etc.

Plastics Recognition Cards

UL iQ for Plastics

UL Blue Card (QMTC2)



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IEC Comparative Tracking Index				
IEC Ball Pressure				
ISO Heat Deflection (1.80 MPa)				
ISO Tensile Strength				
ISO Flexural Strength				
ISO Tensile Impact				
ISO Izod Impact				
ISO Charpy Impact				

Plastics for Additive Manufacturing E########

Guide Information

Process Category: Material Extrusion

View Blue Card Format

Plastics Company Name

Address, City, State, Country

Material Grade Designation

Generic Material Type (&&) "Tradename", furnished as filaments

Color	Min. Thk (mm)	Flame Class	HWI	HAI	GWIT	GWFI	RTI Elec	RTI Imp	RTI Str
All	0.75	HB	3	0	650	960	50	50	50
	1.5	V-2	2	0	700	960	50	50	50
	3.0	V-0	1	0	750	960	50	50	50

Comparative Tracking Index (CTI): 0
Dielectric Strength (kV/mm): 15
High-Voltage Arc Tracking Rate (HVTR): -
IEC Comparative Tracking Index (Volts Max): -
IEC Ball Pressure (°C): -
ISO Tensile Strength (MPa): 20
ISO Tensile Impact (kJ/m²): -

Inclined Plane Tracking (IPT) kV: -
Volume Resistivity (10^x ohm-cm): 9
High Volt, Low Current Arc Resis (D495): -
ISO Charpy Impact (kJ/m²): -
ISO Heat Deflection @1.80 MPa (°C): 160
ISO Flexural Strength (MPa): -
ISO Izod Impact (kJ/m²): -

Process Category: Material Extrusion

Printing Process Designation Number: 1

Build Plane: Horizontal / Vertical
Layer Thickness (mm): 0.20 – 0.40
Infill (%): 100
Post Processing Method: None, 100°C for 3 Hours,
For use with printer: *(Printer Manufacturer and Printer Model)*

Raster Angle (Degrees): -45°/45°
Print Speed (mm/sec): 50

Limited properties and ratings assigned to samples produced by the Additive Manufacturing technique representing a specific set of printing parameters and build strategy. Other print parameters and build strategies may result in significantly different results.

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Report Date: 2019-01-01
Last Revised: 2019-01-01

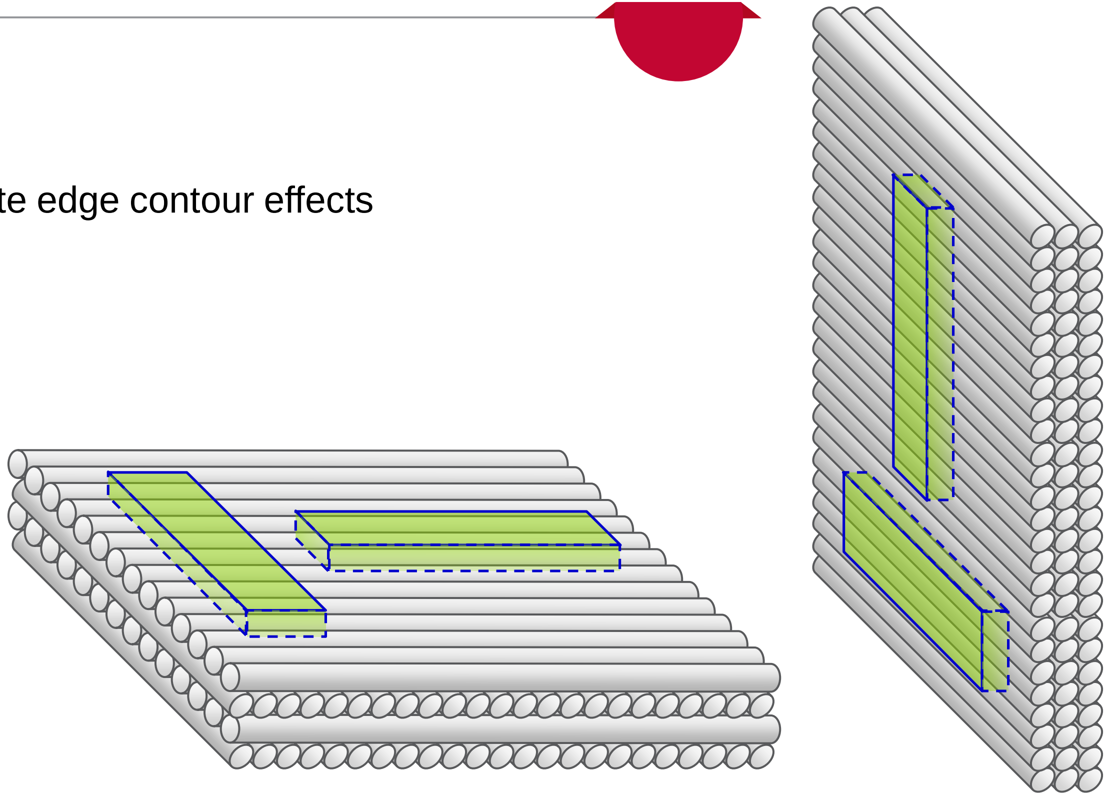
Additive Manufacturing

- Material extrusion
- Powder bed fusion
- Vat photopolymerization
- Binder jetting
- Material jetting
- Sheet lamination

Establishing 3D Printed Material Performance Properties

Test specimens are:

1. 100% infill
2. cut from printed sheets to eliminate edge contour effects
3. horizontal and vertical print plane
4. two orientations per print plane



Certifying 3D Printed Products & Components

If a manufacturer submits a 3D printed part, UL will need to verify:

1. the 3D printed part meets the same performance requirements as a traditionally manufactured part
2. materials used in the 3D printed part are either:
    - Option A: Evaluated as an unlisted component plastic
    - Option B: UL Recognized in the Blue Card program (public, proprietary, or unlisted)
3. the same 3D printing methodology is used to make the part as used for material evaluation

This determination may require consultation with the UL product expert (PDE) or UL Additive Manufacturing staff.

Material Requirements for 3D Printed Products & Components

Material performance requirements are based on the minimum <u>exposed</u> thickness.

- Fully encased part: contour "skin" thickness
- Partial or un-encased part: thinnest wall thickness (infill wall or contour "skin")

Horizontal and vertical printed orientations must meet minimum performance requirements.

3D Printed Prototypes

If a manufacturer submits a 3D printed part, UL will need to verify:

1. tests that can be conducted using the prototype
2. tests that are sufficiently representative of the injection molded part's performance
3. any additional tests that must be conducted using injected molded part specimens (e.g. mold stress)

This determination may require consultation with the UL product expert (PDE) or UL Additive Manufacturing staff to sufficiently understand how the 3D printed part's performance may deviate from that of an injection molded part.

Recognized Material Traceability

How do we ensure that the material originally evaluated ends up, unaltered, in the end product?

Material Manufacturer → **Molder / Processor** → **Original Equipment Manufacturer**

Fabricated Parts Program (QMMY2)

- Traceability program for fabricators (molders & processors)
- Requirements are specified in UL 746D
- Includes requirements for processing conditions for additive manufacturing materials
- No testing required
- May be required in certain categories

In Summary

3D Printing can result in different performance depending on print parameters and print equipment

- UL Yellow Card for materials used in Traditional Fabrication
- UL Blue Card for materials used in Additive Manufacturing

Significant advantages of Plastics Recognition (pre-selection)

- Reduces testing, time-to-market, and saves money
- Assures consistency

UL iQ database provides a useful tool in the selection of materials

Fabricated Part Program

- Ensures consistency and traceability of materials
- Ensures processing methods are followed for additive manufacturing materials

End-products, 3D printed or otherwise, must satisfy the same performance requirements

For additional information:

Thomas.Fabian@ul.com

UL.com/BlueCard

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