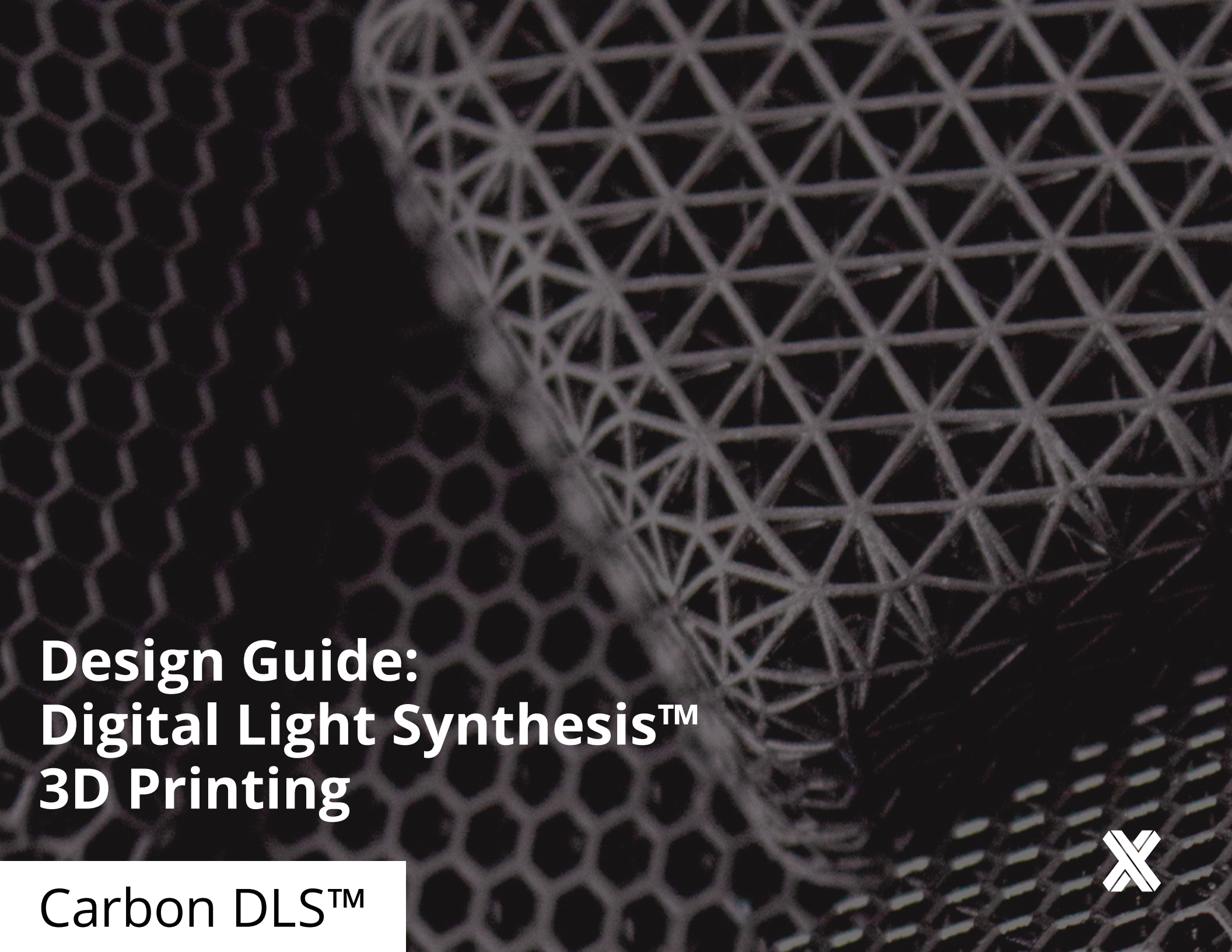


Design Guide: Digital Light Synthesis™ 3D Printing

Carbon DLS™

Overview

Carbon DLS™ uses digital light projection, oxygen-permeable optics, and programmable liquid resins to produce products with end-use durability, resolution and surface finish. This 3D printing technology is called Digital Light Synthesis™, or DLS for short. Another legacy term for the process is Continuous Liquid Interface Production (CLIP). Along with Carbon's custom liquid resins, DLS unlocks new business opportunities and product designs previously impossible, including mass customization and on-demand inventory of end-use products.

Carbon bridges, and sometimes substitutes, for processes like Urethane Casting and Injection Molding service production, because the materials are urethane-based or epoxy-based, giving excellent mechanical properties. There are even elastomer and silicone resins that outperform most additive manufactured rubber-like materials.

What differentiates Carbon DLS from similar processes like Stereolithography (SLA) or PolyJet 3D prints is that the resin has a secondary thermal step which activates dormant epoxies or urethanes, making parts much stronger than UV-curing alone. Additionally, the DLS process is continuous, without stopping layer-by-layer as with most additive manufacturing. This gives the parts isotropic properties, meaning that strength is even regardless of orientation. This is a significant advantage over processes like Fused Deposition Modeling (FDM), where Z-direction features can be much weaker than similar features built in the XY-direction.

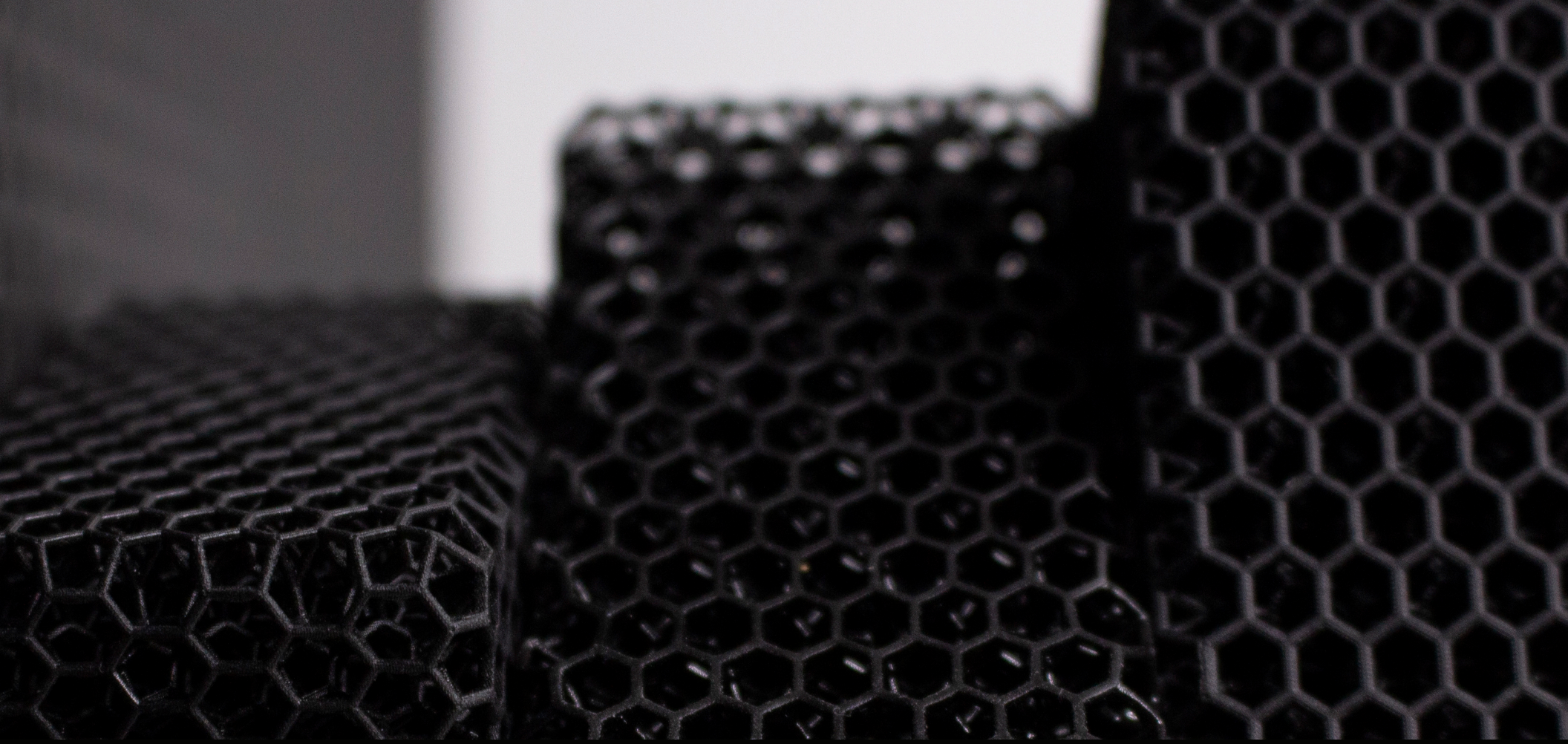


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Build Size



The typical build area is 7.4” x 4.6” x 12.8”. Parts with dimensions exceeding 4” x 4” x 6” will require manual review.

Pro Tip: For production, use the “two-finger” rule, where parts that are about the size of two fingers together (2” x 1” x 3”), or smaller, tend to have the best production economy of scale.

CARBON DLS HAS TWO PRIMARY PRODUCTION MACHINES:

1. Carbon M2 Printer. This replaced the first-gen M1 printer with a larger platform of 7.4” x 4.6” x 12.8”. The projector pixel size is 75 µm. Currently, this is the most available platform for Carbon DLS printing.

2. Carbon L1 Printer. The L1 is currently in limited production and boasts a larger build size than the M2. The exact measurements of the L1 are not yet disclosed, but it is reported to have 5X the build area of the M2.





General Tolerances

- +/- 0.005” for the first inch is typical, plus +/- 0.002” for every inch thereafter. However, Xometry does not guarantee tolerances on the first attempt of a new design. Tolerance expectations can vary across different materials (e.g. elastomeric versus rigid materials).

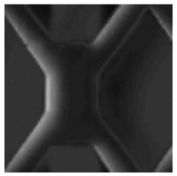
- Stresses during build, support strategy, and other geometry considerations may cause deviation in tolerances and flatness.

- Parts with thicker geometries, flat or broad parts, and parts with uneven wall thicknesses may be prone to significant deviations or warp.

- Improved tolerances may be possible with a manual quote review, after successful completion of a prototype build, and must be approved on a case-by-case basis.

Materials

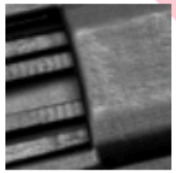
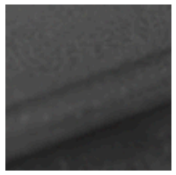
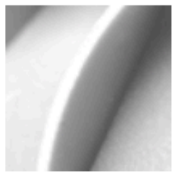
CARBON DLS MATERIALS

Image	Resin	Ultimate Tensile Strength	Elongation at Break	Tensile Modulus	Shore Hardness	Impact Strength	Heat Deflection Temp**	Comparable Thermoplastic
	**CE 221**	92 MPa*	3.5%	3870 MPa*	92D*	15 J/m	231°C*	15% Glass-filled nylon
	**EPU 40**	10.2 MPa	310%*	N/A	68A	N/A	N/A	Thermoplastic polyurethane (TPU)
	**EPU 41**	6.2 MPa	>130%	N/A	73A	N/A	N/A	Thermoplastic polyurethane (TPU)

The table lists Carbon Materials, known as resins, their properties, and comparable plastics.
(Source: Carbon3D)

Materials

CARBON DLS MATERIALS

	**EPX 82**	82 MPa	5.9%	2800 MPa	89D	44 J/m*	115°C	20% glass-filled PBT
	**FPU 50**	29 MPa	280%	831 MPa	71D	40 J/m	78°C	Polypropylene (PP)
	**RPU 70**	45 MPa	100%	1900 MPa	80D	22 J/m	70°C	ABS or PC-ABS
	**SIL 30**	3.4 MPa	330%	N/A	35A	N/A	N/A	TPE
	**UMA 90**	46 MPa	17%	2000 MPa	86D	33 J/m	51°C	NA

* Indicates the highest value in its category

The table lists Carbon Materials, known as resins, their properties, and comparable plastics.
(Source: Carbon3D)

EPX 82 Chemical Compatibility

EPX 82, an epoxy-based material, has been tested with the following chemical compatibility results (Source: Carbon3D). These results indicate EPX as an acceptable material for automotive and similar applications.



Liquids	Liquid Submersion Temp. for 0.5 hr (C)	EPX 82 Modulus (Mpa)	EPX 82 Ultimate Tensile Strength (Mpa)	EPX 82 Elongation to Break (%)	STDEV Modulus	STDEV UTS	STDEV Elongation	Retained Tensile Modulus	Retained Ultimate Tensile Strength	Retained Elongation to Break
Control	NA	2960	67.9	14.7	170	0.242	1.866	100%	100%	100%
Gasoline	23	2860	66.5	17.5	93	0.4	1.207	97%	98%	119%
Diesel	23	2890	67.7	14.9	95.3	0.403	2.449	98%	10%	101%
E85	23	2850	67.3	16.7	148	0.233	1.522	96%	99%	114%
Diesel Exhaust Fluid	23	2840	65.7	10.7	74.4	0.422	2.531	96%	97%	73%
Engine Oil	50	2960	68.1	15.5	141	0.712	1.54	100%	100%	105%
Power Steering Fluid	50	2870	66.1	18.4	80.4	0.562	1.26	97%	97%	125%
Automatic Transmission Fluid	50	2870	67.9	15.3	140	0.677	1.885	97%	100%	104%
Engine Coolant 50/50	50	2830	65.8	17.1	163	0.452	1.84	96%	97%	116%
Brake Fluid DOT 4	50	2850	66.5	10.7	191	0.466	2.432	96%	98%	73%

Sterilization

The following materials can be sterilized with the listed processes.

Material	Steam / Autoclave	EtO (Ethylene Oxide)	Electron Beam Irradiation	Gamma Ray Irradiation	Notes
CE	✓**	✓	✓	✓	**Limited Cycles
EPX	✓	✓	✓	✓	
RPU	✓*	✓	✓	✓	*Some changes in mechanical properties
FPU	?	✓	✓	✓	
EPU	?	✓	✓	✓	
SIL	?	✓	✓*	✓*	*Some changes in mechanical properties

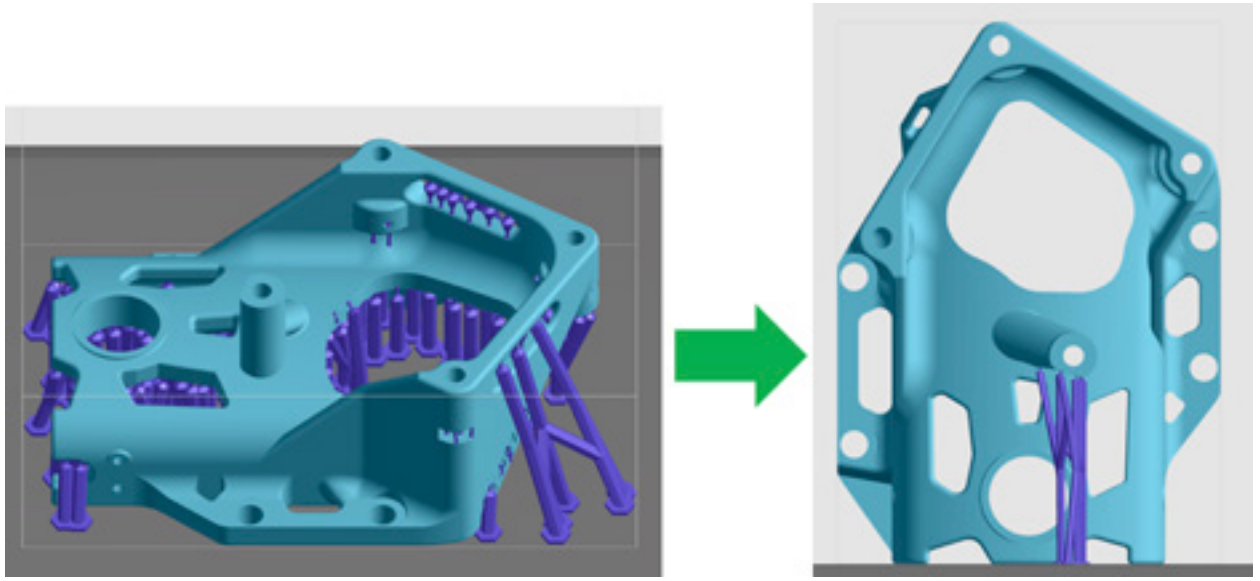
Biocompatibility Results (Initial Testing)

Below is the initial testing* results of Carbon DLS materials for biocompatibility. Note these are non-conclusive but can be helpful when determining a material approach for production.

- **Cytotoxicity:** All resins pass.
- **Irritation:** UMA, CE, EPX, RPU, EPU, and SIL pass. Other resins have not been tested.
- **Sensitization:** UMA, CE, EPX, RPU, EPU, and SIL pass. Other resins have not been tested.

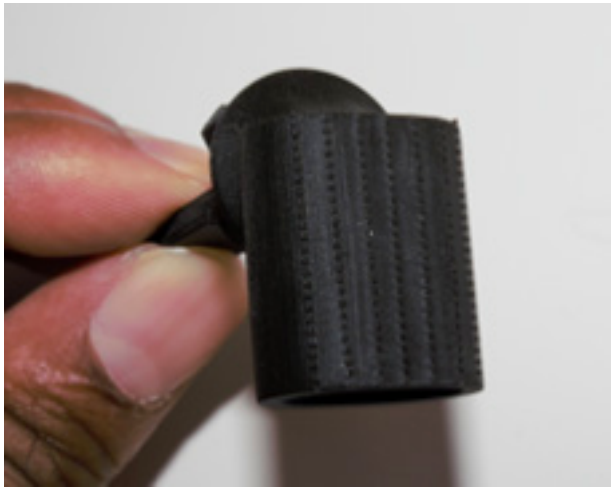
Tests conducted in Q4 2016 by NAMSA;
Passed ISO 10993-5 and -10 for skin and mucosal contact.

Build Orientation



Build orientation is determined by Xometry with the primary goal of optimizing prominent features or details while minimizing build height and support usage. Adding additional supports can often be justified if it helps to effectively reduce the chance of failures during the build.

Due to the isotropic nature of Digital Light Synthesis™, orientation may not affect the mechanical properties of the part but will dictate how and where support structure is used. In general, parts designed for DLS that have large broad flat sections are oriented at a minimum of 15-20 degrees from the platform to minimize cross-section per any given layer position.



Support

Support structure is made of the same material as the part and is generated to be easily removed by hand with minimal post-processing after the build is complete.

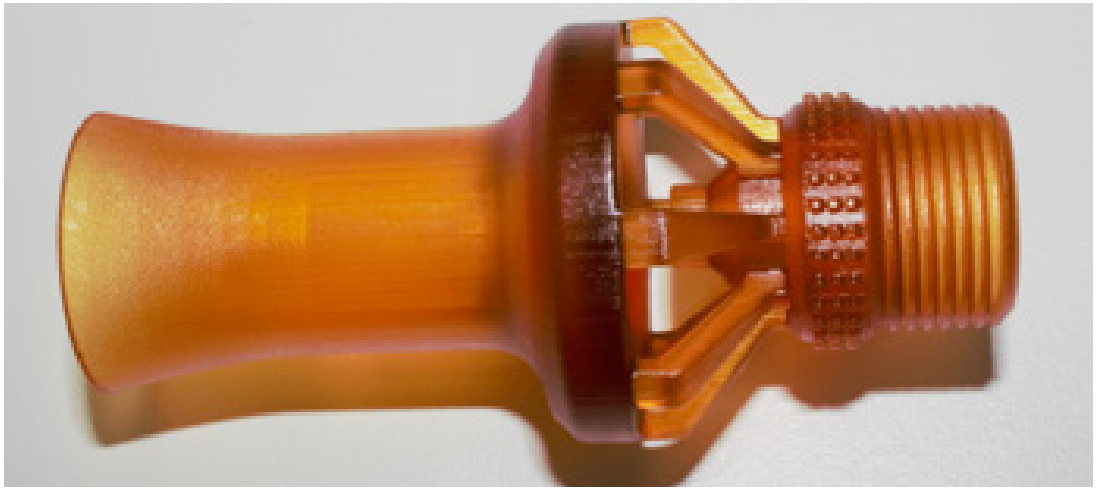
Areas with support structure may show raised bumps where the structure was removed. In certain materials, like EPX, SIL, and EPU, supported areas may be more visible because post-processing options are limited. This may affect areas like O-ring grooves and internal features if support is required.

Surface Finish

Standard (As-Printed)

Parts built with DLS technology will typically have a matte to semi-gloss surface finish depending on feature direction. DLS is the only 3D printing process where traditional layer stepping is may not be present. Extended protrusions will show vertical lines in the part that are parallel to the direction of growth. Supports are removed and mitigated as required.

For heavily contoured features, a pixel-like effect is often seen on the part. These features will be smooth or matte to the touch.





Textures

Textures can be applied in-CAD using various design software. Because of the continuous printing process, matte and geometric textures can be aesthetically pleasing and help mitigate cosmetic variations on the surface.

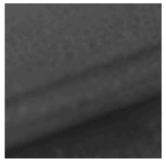
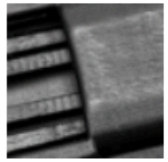
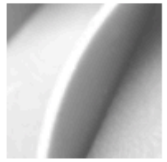
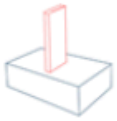
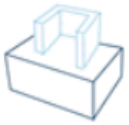
Designing Features for DLS

The guidelines below will help assure that a consistent and repeatable product printed using Carbon DLS.

Note: designing for the minimum feature size in ANY process is not recommended.

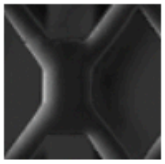
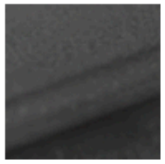
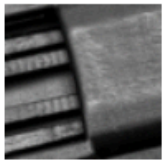
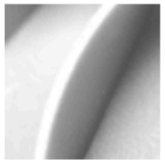
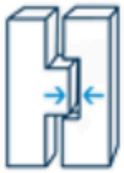
Wall Thickness

Note that EPX requires more than triple the minimum wall thickness as most materials.

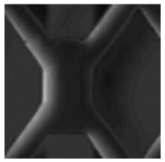
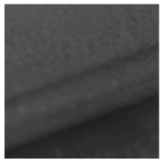
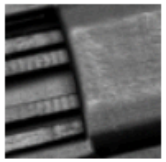
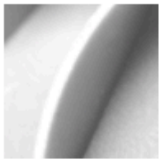
Minimum Wall Thickness for Carbon DLS Materials								
Icon	**Feature**	**RPU 70**	**EPU 40/41**	**FPU 50**	**CE 221**	**EPX 82**	**UMA 90**	**SIL 30**
	Unsupported Walls	0.3 mm *2.5 mm	0.4 mm *2.5 mm	0.4 mm *2.5 mm	0.3 mm *2.5 mm	1.5 mm *2.5 mm	0.3 mm *2.5 mm	0.5 mm *2.5 mm
	Supported Walls	0.2 mm *1.0 mm	0.3 mm *1.0 mm	0.3 mm *1.5 mm	0.2 mm *1.0 mm	1.3 mm *1.5 mm	0.2 mm *1.0 mm	0.3 mm *1.5 mm
*Recommended Feature Size								

Feature Size

Although DLS prints are isotropic, the orientation of the part during building will dictate minimum feature sizes.
In general, keeping any feature above 1mm is recommended. Note the same rules apply for holes and gaps.

Minimum Feature Sizes for Carbon DLS Materials								
Icon	**Feature**	**RPU 70**	**EPU 40/41**	**FPU 50**	**CE 221**	**EPX 82**	**UMA 90**	**SIL 30**
	Positive Feature, XY	0.3 mm *0.4 mm	0.4 mm *0.5 mm	0.4 mm *0.5 mm	0.3 mm *0.4 mm	0.3 mm *0.3 mm	0.3 mm *0.4 mm	0.5 mm *1.0 mm
	Negative Feature, XY	0.4 mm *0.5 mm	0.4 mm *0.5 mm	0.4 mm *0.5 mm	1.0 mm *1.0 mm	0.4 mm *0.6 mm	0.8 mm *0.9 mm	1.0 mm *2.0 mm
	Positive Feature, Z	0.1 mm *0.2 mm	0.1 mm *0.2 mm	0.1 mm *0.2 mm	0.1 mm *0.2 mm	0.1 mm *0.2 mm	0.1 mm *0.2 mm	0.5 mm *1.0 mm
	Negative Feature, Z	0.5 mm *0.6 mm	0.4 mm *0.5 mm	0.4 mm *0.5 mm	0.6 mm *0.7 mm	0.5 mm *0.9 mm	0.7 mm *0.8 mm	1.0 mm *2.0 mm
	Clearance Between Mating Parts	0.3 mm *0.4 mm	0.3 mm *0.5 mm	0.3 mm *0.5 mm	0.4 mm *0.8 mm	0.3 mm *0.4 mm	0.3 mm *0.5 mm	0.4 mm *0.5 mm
*Recommended Feature Size								

Engraving, Embossing, and Text Sizes

Minimum Engraving, Embossing, and Text for Carbon DLS Materials								
Icon	**Feature**	**RPU 70**	**EPU 40/41**	**FPU 50**	**CE 221**	**EPX 82**	**UMA 90**	**SIL 30**
	Engraving Depth	0.1 mm *0.3 mm	0.1 mm *0.3 mm	0.1 mm *0.3 mm	0.2 mm *0.4 mm	0.1 mm *0.3 mm	0.1 mm *0.3 mm	0.3 mm *0.5 mm
	Embossing Height	0.1 mm *0.3 mm	0.1 mm *0.3 mm	0.1 mm *0.3 mm	0.2 mm *0.4 mm	0.1 mm *0.3 mm	0.1 mm *0.3 mm	0.3 mm *0.5 mm
	Text Size, Engraved	1.5 mm *3.0 mm	1.5 mm *3.0 mm	1.5 mm *3.0 mm	1.5 mm *3.0 mm	1.5 mm *3.0 mm	1.5 mm *3.0 mm	2.0 mm *3.5 mm
	Text Size, Embossed	1.5 mm *3.0 mm	1.5 mm *3.0 mm	1.5 mm *3.0 mm	1.5 mm *3.0 mm	1.5 mm *3.0 mm	1.5 mm *3.0 mm	2.0 mm *3.5 mm
*Recommended Feature Size								

Drafts

Drafting extrusions outwards is another way to drastically increase strength due to the resulting increase in area at the base. This can also be useful for embossed text and tab features.

Confined Hollows

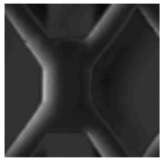
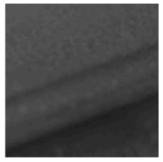
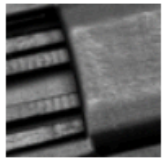
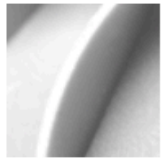
Carbon DLS prints solid models. Any confined hollows will contain trapped uncured resin resulting in defects. Escape holes are required for internal areas to allow for material to be removed, as well as mitigate any suction a feature may cause during building.

Fillets

Adding fillets where possible is typically recommended for any 3D printing process. Fillets help mitigate acute stress areas on parts and with the DLS process, can ensure smooth build transitions between features.



Overhangs

Overhang and Unsupported Angle Rules for Carbon DLS Materials								
Icon	**Feature**	**RPU 70**	**EPU 40/41**	**FPU 50**	**CE 221**	**EPX 82**	**UMA 90**	**SIL 30**
	Max Overhang	3.0 mm *2.0 mm	2.0 mm *1.0 mm	4.0 mm *2.0 mm	4.0 mm *3.0 mm	4.0 mm *2.0 mm	4.0 mm *3.0 mm	2.0 mm *1.0 mm
	Unsupported Angle from Vertical	50° *40°	50° *40°	50° *40°	50° *40°	50° *40°	50° *40°	50° *40°
*Recommended Feature Size								

Off-Gassing

Post-cured materials can sometimes off-gas. Notably, FPU 50 can have a pine-like scent depending on its size and cross-section. Even with some longer post-thermal cycles (e.g. 12 hours), the smell may be persistent. Often this will dissipate over time but may not always fully disappear.



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