White Paper

Beyond the Data Sheet: Unidirectional Material Testing May Mislead Manufacturing

Abstract

This white paper was motivated by claims of superior material properties by FFF (fused filament fabrication) competitors despite internal Stratasys testing that demonstrated otherwise. This incongruity between published and demonstrated specifications stems from differences in the toolpaths and build orientation of mechanical test specimens between Stratasys test methods and the competitor's. When switching from the standard toolpaths used by Stratasys to the optimized unidirectional toolpaths used by the competitor, Stratasys FDM® Nylon-CF10 showed a 160% increase in the heat deflection temperature (HDT), 152% increase in the tensile modulus, and 94% increase in the tensile yield strength over our actual published specifications. Printing mechanical samples with unidirectional toolpaths is appropriate to show the maximum strength of a carbon fiber filled material, but is not representative of the material strength within the typical FFF part.

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Introduction

At Stratasys, mechanical properties are tested in a consistent and transparent manner **(see the Stratasys Materials Testing Procedure for standard testing procedures for FDM)**. The toolpaths follow our default toolpath generation where the layers are at a "45°/-45°" orientation with respect to each other. This means that the first raster layer is 45° in the **XY** plane and the next layer is perpendicular to that layer (-45°). For a simple rectangular geometry, this would be alternating between Layer A and Layer B in Figure 1. Testing mechanical properties with 45°/-45° rasters produces more isotropic performance in the **XY** plane and represent the toolpaths utilized in large parts, such as those used in manufacturing.

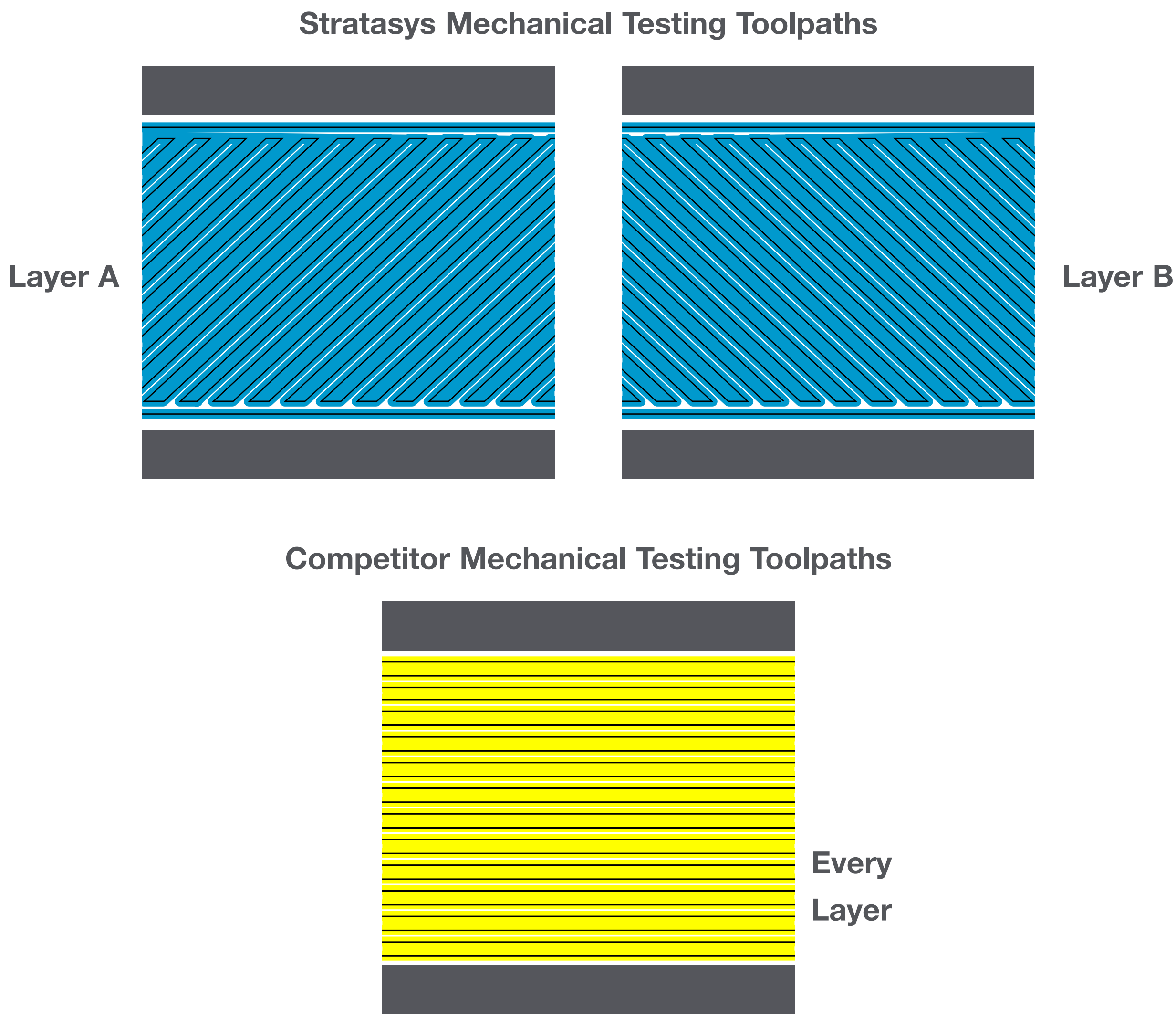

Figure 1 - Difference between Stratasys and competitor mechanical testing toolpaths. Stratasys has rasters at a 45° angle with a perpendicular offset between layers. Competitors have unidirectional toolpaths that are the same on every layer.

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When Stratasys FDM parts are built, layers are added one at time, which results in reduced interlayer bonding and decreased strength in the vertical (**Z**) direction compared to the **XY** plane. When printing a filled material, such as Nylon-CF10 or ABS-CF10, this is accentuated as the carbon fiber aligns in the toolpaths and increases the strength within the **XY** plane. Stratasys tests mechanical properties in the On-Edge (**XZ**) and Upright (**ZX**) orientations (see Figure 2). By presenting the upright (**ZX**) data, the weakest condition is presented so that parts can be designed with knowledge of the "worst case" mechanical performance to allow for plenty of safety margin.

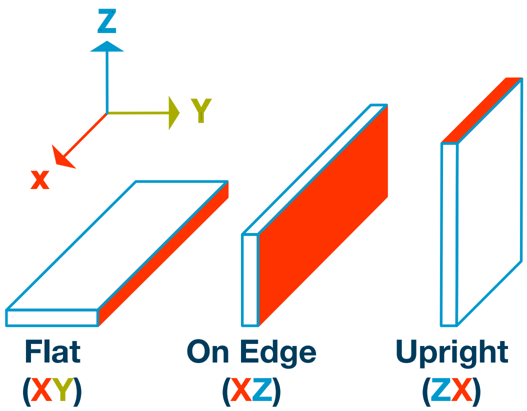

Figure 2- Print Orientations.

Competing FFF manufacturers tend to select and present mechanical and physical properties from toolpaths optimized for the test setup. An example is a competitor providing data only for the flat (**XY**) orientation with unidirectional toolpaths like those shown in Figure 1. With a filled material, the aligned carbon fibers help to increase the strength within the **XY** build plane. This method of optimizing toolpaths is appropriate to show the maximum strength for filled materials, but should be used with caution as it is not representative of typical part toolpaths and strength.

To show the improved performance with unidirectional toolpaths, Stratasys printed heat deflection temperature (HDT), flexural, tensile, and notched impact samples in ABS-CF10 and Nylon-CF10. This white paper will show the procedures and improved performance of the materials when utilizing unidirectional toolpaths.

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Test Procedure

Insight™ software was used to prepare build files with a unidirectional toolpath for HDT, tensile, flexural, and impact test specimens. Specimens were prepared for both ABS-CF10 and Nylon-CF10 materials. Specific details on the processing parameters and test methods can be found within the subsections below. Unless specified, default processing parameters and standards were followed. Comparative samples in these materials with standard 45°/-45° rasters followed the procedures in the **Stratasys Materials Testing Procedure** for file processing.

All build packs were created with Control Center™ software using the process in the Stratasys Material Testing Procedure. ABS-CF10 samples were produced on an F370® and Nylon-CF10 samples were produced on an F370®CR. For each material type, all material was from the same lot. QSR Support™ was used with both model materials. The Nylon-CF10 samples were tanked for 4-6 hours to remove the QSR support. The support material was manually removed from the ABS-CF10 specimen.

For tensile, flexural, and impact specimens, 10 specimens were tested for each material and toolpath type. For HDT, triplicate testing was performed for each material and pressure [0.45 MPa and 1.8 MPa (66 and 264 psi)]. Details of the physical and mechanical testing for this study are listed below.

See Appendix A for a full list of software versions and test equipment.

Heat Deflection Temperature Testing

HDT test specimens were 127 mm x 12.7 mm x 5.1 mm (5 in. x 0.5 in. x 0.2 in.) samples, printed in the flat (**XY**) orientation with unidirectional toolpaths. To do this, the samples were produced as a “racetrack” of continuous contours by connecting two length-oversized samples connected with rounded ends as shown in Figure 3. The semi-circular ends were cut to size by removing the semi-circular ends at the locations indicated in Figure 3.

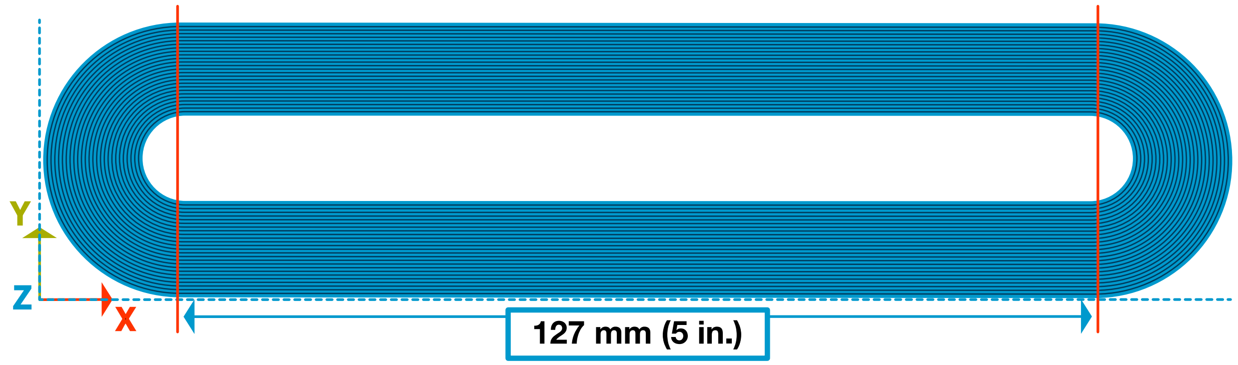

Figure 3- Racetrack with two attached HDT samples to allow for continuous contours. The semi-circles were cut off to leave just the HDT specimen.

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While processing in Insight, the toolpath parameters were modified to specify 15 contours and a contour width of 0.0210 in. for Nylon-CF10 and 0.0208 in. for ABS-CF10. When the default contour width of 0.02 in. was used, a small raster appeared in the middle of the sample (see Figure 4). Visually there is a minor gap in the ABS-CF10 sample toolpaths in Insight, but when printed the sample was presenting overfill on the upper surface until the contour width was reduced to 0.0208 in. An example of the Insight settings for the HDT samples is shown in Figure 5.

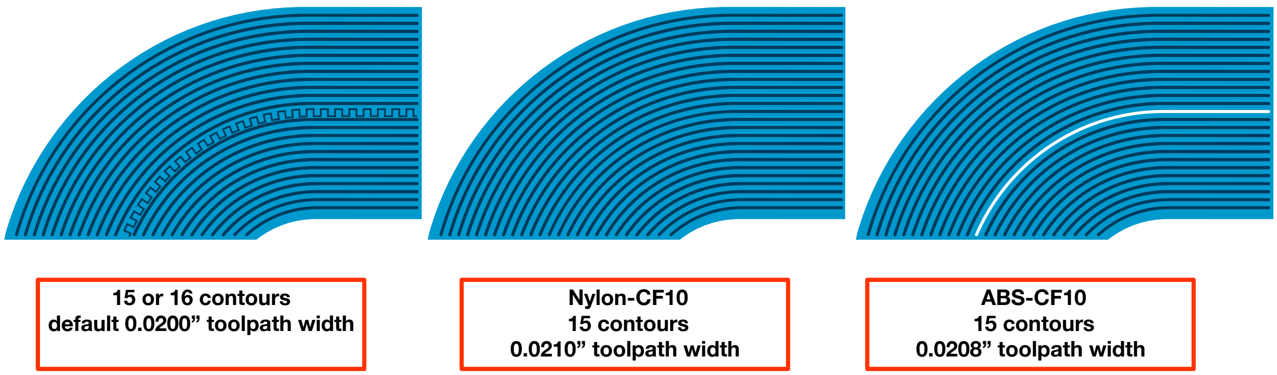
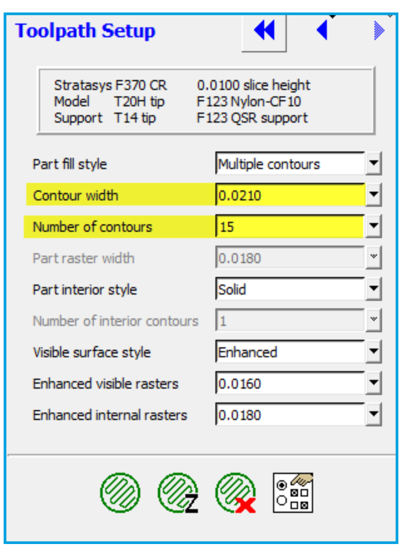


Figure 4- Example of contours on the HDT racetrack. When default contour width was used, a small raster pattern was present in the middle of the sample. For ABS-CF10 and Nylon-CF10, the contour width was widened by 0.0008-0.0010” for completely unidirectional toolpaths.



The unidirectional HDT samples were tested at 0.45 and 1.8 MPa (66 and 264 psi). Three samples were tested per material, per pressure, following ASTM D648 Procedure B with a span length ~51 mm (~2 inches). All HDT samples were conditioned for a minimum of 16 hours at 70 ± 0.5 ºC (158 °F ± 0.9 °F) in a vacuum oven at less than 100 mbar prior to testing.

Figure 5 - Example of modified toolpath parameters for HDT. Modified parameters are highlighted in yellow.

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Tensile Strength

Tensile mechanical tests were performed on ASTM D638 Type I samples, thickness = 3.3 mm (0.130 in.). To create the unidirectional toolpaths, all the curves of the tensile specimen were added to a custom group in Insight. The custom group was needed so that a delta angle of 0° could be applied to prevent the raster section of the coupon from being perpendicular on alternating layers. Within the custom group, modified toolpaths used six contours and the Infill Angle Controls set with a Start Angle of 0° and Delta Angle of 0°. For Nylon-CF10, contour width was the default of 0.02 in. For ABS-CF10, Contour width was 0.0198 in. as the part appearance was overfilled at the default of 0.02 in. Figure 6 shows the toolpaths of the tensile coupons with the unidirectional toolpaths in place for the necked region. Figure 7 shows the toolpath parameters that were modified within the applied custom group for the part.

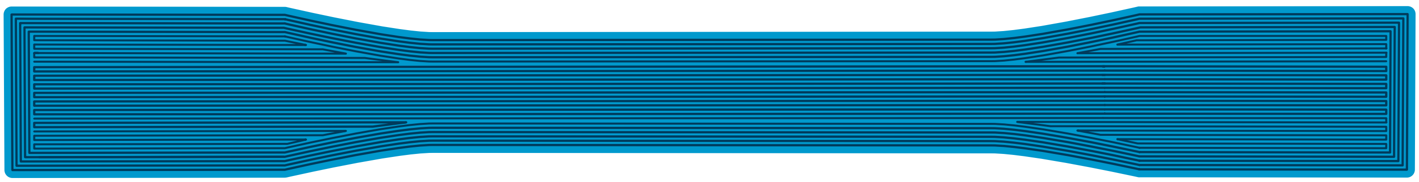
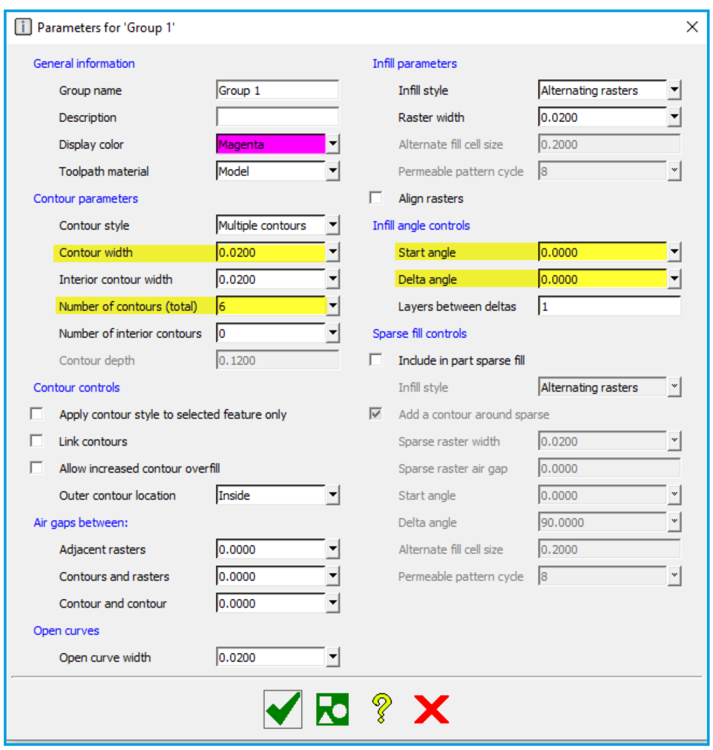


Figure 6- Toolpaths of D638 tensile coupon with unidirectional toolpaths within the necked region.



Tensile mechanical tests were performed per ASTM D638 with a cross-head speed of 0.2 in./min. The tensile modulus is calculated on the stress-strain values from 15% to 35% of the max load. All samples were conditioned for a minimum of 40 hours at 23 ± 2 °C (73 °F ± 3.6 °F) and 50 ± 10% RH prior to testing.

Figure 7- Example of the custom groups for unidirectional tensile coupons. Modified parameters are highlighted in yellow for Nylon-CF10.

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Flexural Strength

Flexural mechanical tests were performed to ASTM D790 samples, 10.2 mm x 6.1 mm x 152.4 mm (0.4 in. x 0.24 in. x 6 in.). Like the HDT samples, the flexural strength coupons were created from a "racetrack" with only contours; the ends were later cut off (see Figure 8). With the objective of creating fully filled coupons, minor adjustments were made to the contour width to fill the coupon and then reduced if the coupon was overfilled when printed. For the modified toolpath parameters in Insight, contours were set to 10 and the contour width was 0.0201 in. for Nylon-CF10 and 0.02005 in. for ABS-CF10.

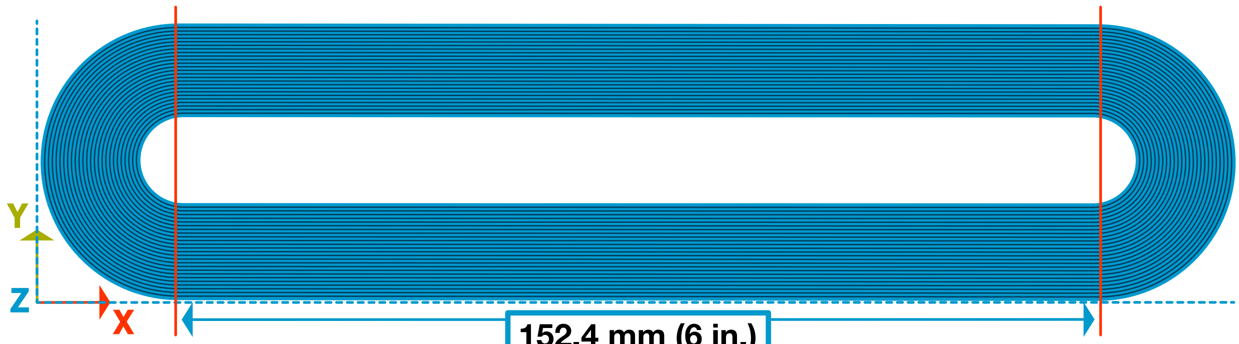

Figure 8- Racetrack with two attached flexural samples to allow for continuous contours. The semi-circles were cut off to leave just the flexural specimen.

Flexural mechanical tests were performed to ASTM D790 samples using Procedure A with a span length of ~2 in. and a 0.01 in./in./min strain rate. All samples were conditioned for a minimum of 40 hours at 23 ± 2 °C (73 °F ± 3.6 °F) and 50 ± 10% RH prior to testing.

Izod Impact (Notched)

The Izod impact samples were performed on ASTM D256 samples, thickness = 3.175 mm (0.125 in.). The toolpaths were created similar to the tensile specimen with a custom group so the raster delta angle could be set to 0°. The custom group was set with a single contour, solid infill, an infill angle control start angle of 0° and delta angle of 0°, and default contour and raster widths. This resulted in a coupon infill like that in Figure 9 on each layer.

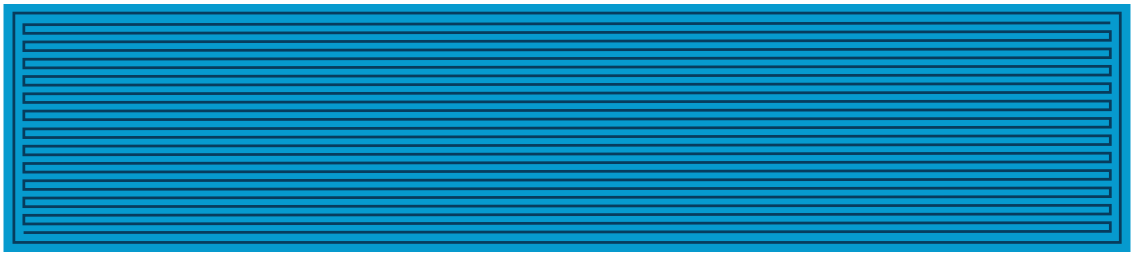

Figure 9- Toolpaths of the unidirectional Izod impact specimen.

Izod notched tests were performed per ASTM D256 with a 2 or 16.1 ft*lb pendulum capacity using Method A. The notch was created after printing per ASTM D256. All samples were conditioned for a minimum of 40 hours at 23 ± 2 °C (73 °F ± 3.6 °F) and 50 ± 10% RH prior to testing.

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Results and Analysis

While looking at the unidirectional test results, existing data from the material data sheets or other datasets that were tested per the Stratasys Materials Testing Procedure are included to show comparisons to the mechanical performance. Raw data for the unidirectional data will be available upon request. Tables with the Imperial units can be found in Appendix B.

HDT Testing

The HDT is the temperature at which a material starts to soften or deform under load, indicating its heat resistance. It helps determine the maximum temperature a material can withstand without significant deformation or failure.

The HDT data for ABS-CF and Nylon-CF is shown in Table 1. The unidirectional toolpaths in ABS-CF10 show incremental increases over the standard 45°/-45° toolpaths at both pressures. Nylon-CF10 shows significant increases of around 160% between the unidirectional and the standard toolpaths. It is also noteworthy that the unidirectional toolpaths are higher than the as-molded HDT data. By aligning the carbon fibers along the toolpaths, rather than how they more randomly disperse during the injection molding process, there is a 13%-40% increase in the achieved HDT.

	HDT (°C)			
	ABS-CF10		Nylon-CF10	
	Low (0.45 MPa)	High (1.8 MPa)	Low (0.45 MPa)	High (1.8 MPa)
Unidirectional Toolpaths (XY orientation)	117	112	153	133
Standard 45/-45 Toolpaths (XY orientation)	112	111	58	52
As-Molded	100	99	109	105

Table 1 - HDT of ABS-CF10 and Nylon-CF10

Tensile Strength

Tensile testing evaluates a material's strength, ductility, and elongation by pulling on the ends of the specimen until it breaks. The tensile data for the unidirectional toolpaths are in Table 2, as well as tensile data for **XY** coupons with normal 45°/-45° toolpaths from the same machines and material lots as the unidirectional ones. For both materials, there is an increase in the tensile modulus, yield strength, and stress at break, as well as a decrease in the elongation values with the unidirectional toolpaths. This makes sense because the carbon fibers aligned in the axis under tension help to improve the strength, but decrease the ability for the matrix material to elongate in the axis of tension.

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For ABS-CF10, the unidirectional toolpaths cause a 25% increase in the yield strength and stress at break and a 71% increase in the elastic modulus over the standard toolpaths. With Nylon-CF10, the elastic modulus increases by 152% and the yield strength by 94% with the unidirectional toolpaths.

Additionally, the tensile data is relatively tight as illustrated in Figure 10 - The tensile yield strength is increased by using unidirectional toolpaths. The Coefficient of Variation (COV), which is defined as the standard deviation divided by the mean, is less than 4% for all of the tensile modulus and yield strength for the XY tensile data.

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	ABS-CF10		Nylon-CF10	
Toolpaths	Unidirectional	Standard 45/-45	Unidirectional	Standard 45/-45
Modulus of Elasticity (GPa)	5.22	3.04	6.03	2.39
Yield Strength (MPa)	44.9	35.8	68.1	35.1
Elongation at Yield (%)	1.2	3.0	4.0	5.6
Stress at Break (MPa)	44.6	35.6	64.4	20.0
Elongation at Break (%)	1.2	3.0	5.1	8.2

Table 2 - Tensile Data of ABS-CF10 and Nylon-CF10 in the XY Orientation

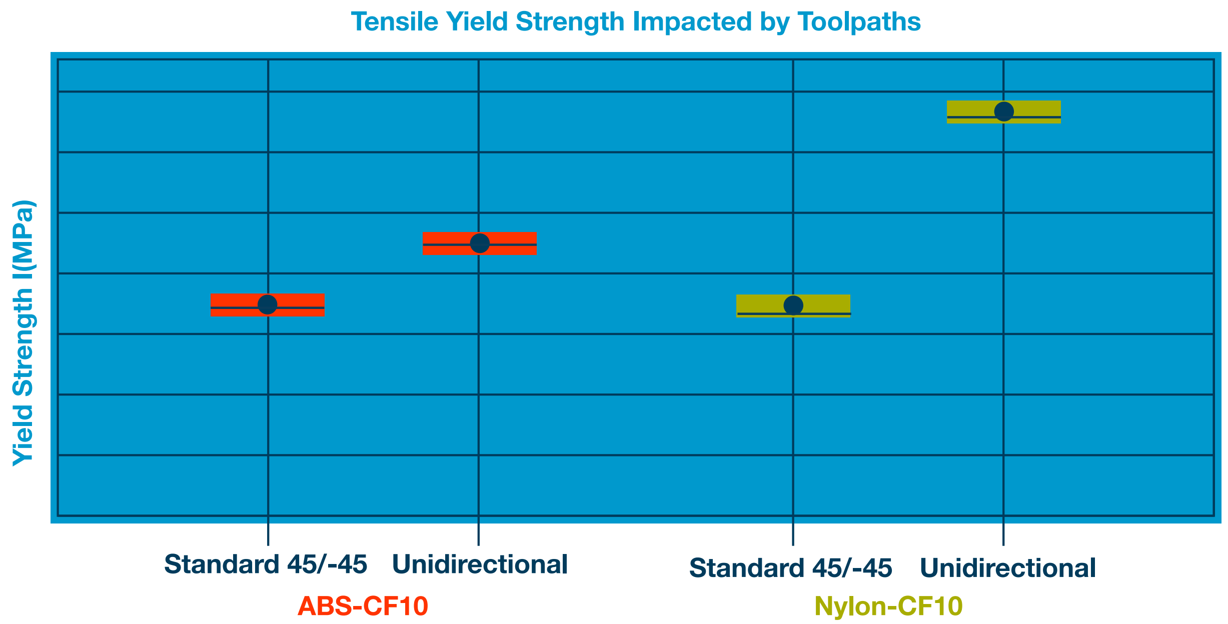

Figure 10- The tensile yield strength is increased by using unidirectional toolpaths.

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Flexural Strength

Flexural strength testing evaluates a material's ability to resist bending or deformation under a three-point loading configuration. It indicates the material's resistance to breaking or cracking when subjected to bending forces, providing insight into its structural integrity and ability to withstand loads in real-world applications. The unidirectional flexural strength data is shown in Table 3 with the flexural strength shown in Figure 11. The data from the 10 samples is very repeatable with a COV less than 4% for flexural modulus and flexural strength a break for each material.

Flexural Strength of XY Specimen with Unidirectional Toolpaths Nylon-CF10		
	ABS-CF10	Nylon-CF10
Modulus of Elasticity (GPa)	4.96	6.96
Flexural Strain at Break (%)	2.6	3.4
Flexural Stress at Break (MPa)	89.3	138.2

Table 3-Flexural Strength of ABS-CF10 and Nylon-CF10 in the XY Orientation with Unidirectional Toolpaths

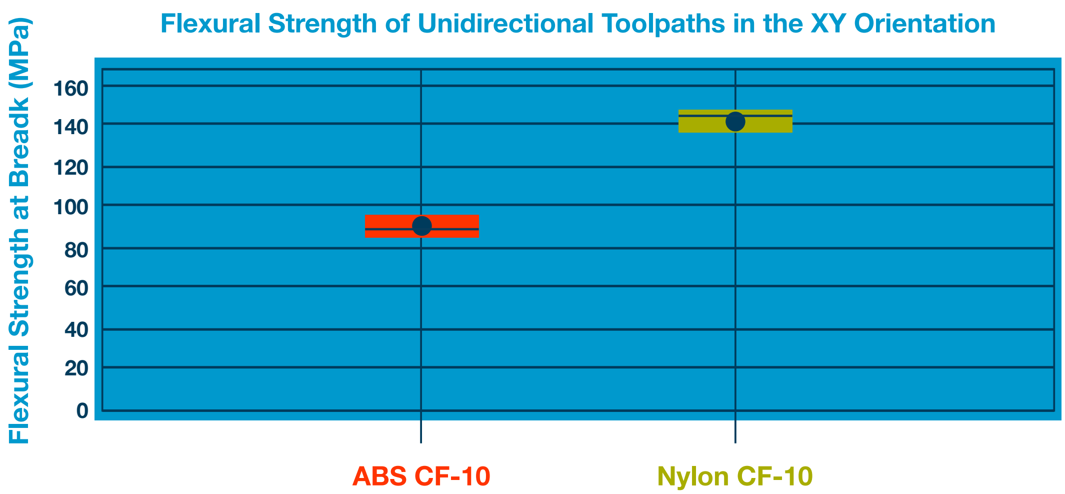

Figure 11- Flexural Stress at Break of Unidirectional Toolpaths in the XY orientation.

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Izod Impact (Notched)

Notched Izod testing is a method used to assess a material's impact resistance by measuring the energy required to break a notched specimen subjected to a pendulum impact. It indicates the material's ability to withstand sudden impact or shock loads and provides insight into its toughness and fracture resistance. This test is valuable in material selection for applications where impact or dynamic loading is a concern, helping to ensure the chosen material can withstand potential impacts without catastrophic failure.

Table 4 contains the impact data for ABS-CF10 and Nylon-CF10. The data from the standard toolpaths is the data from the material datasheet. By printing unidirectional toolpaths in the flat orientation, there is a 54% increase and 26% increase in the highest reported impact strength of ABS-CF10 and Nylon-CF10, respectively. For FDM, reduced interlayer bonding between layers causes the vertical (**Z**) direction to be weaker than the **XY** (flat) plane. If Stratasys were to just report the unidirectional data, Nylon-CF10 impact strength would be 7.5 times higher than the upright (**XZ**) orientation and ABS-CF10 impact strength would be 3.9 times higher. This would drastically misrepresent the actual material strength in a real part where dynamic loading is the concern. When designing parts, the material strength of **Z** direction needs to also be taken into account to ensure proper design limits and safety factors.

Printing unidirectional toolpaths in the flat orientation results in a 54% increase in ABS-CF10 impact strength and a 26% increase in Nylon-CF10 impact strength, but this would misrepresent the actual material strength in real parts, where vertical strength is crucial.

Proper design considerations should account for X,Y, and Z directional strength for safety and functionality.

Izod Impact Strength of ABS-CF10 and Nylon-CF10 (J/m)			
Print Orientation	Toolpaths	ABS-CF10	Nylon-CF10
Flat (XY)	Unidirectional	79.2	272
OnEdge (XZ)	Standard 45°/-45°	51.4	202
Upright (ZX)	Standard 45°/-45°	20.3	36.3

Table 4-Izod Impact Strength Data

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Comparison to Nearest Competitor

This white paper was motivated by claims from competitors to have superior material properties. When testing our materials with unidirectional toolpaths, a clearer picture is presented with a more appropriate comparison. To illustrate, Table 5 summarizes the unidirectional mechanical data for ABS-CF10 and Nylon-CF10 right beside the reported mechanical data from a competitor. The competitor material data is directly from the latest competitor's material datasheet (dated early 2022), unless noted otherwise.

While looking at Table 5, one should take into account the breadth of data that is being represented. For the competitor materials, each datapoint represents triplicate testing, so just 3 samples. For ABS-CF10 and Nylon CF10, the HDT testing represents 3 samples, but the tensile, flexural, and impact material properties contain data from 10 specimens. For typical mechanical testing on Stratasys FDM material datasheets, the data represented is 30 specimens minimum (3 machines x 10 coupons). So Stratasys materials are represented by three times as much data, but our typical material datasheets contain ten times as much data relative to this competitor.

This white paper was motivated by claims from competitors to have superior material properties. When testing our materials with unidirectional toolpaths, a clearer picture is presented with a more appropriate comparison.

For tensile test results, the Stratasys materials have higher tensile modulus and tensile strength, whereas the competitor materials have greater elongation at break. This is the tradeoff; by increasing the material strength and ability to withstand deformation at a given force, the amount of give or ability to elongate is decreased. The tensile modulus of ABS-CF10 and Nylon-CF10 is roughly twice that of the competitor materials, indicating that the Stratasys materials are stiffer and able to withstand greater forces with less deformation.

For the flexural test results, ABS-CF10 and Nylon-CF10 have greater flexural modulus and stress at break than the competitor's materials. This indicates that these materials are more able to withstand the 3-point bend loading with less deformation for a given load. The carbon fibers of ABS-CF10 and Nylon-CF10 are longer than that of the competitor's materials which would help in their ability to resist flexing under a given load.

For HDT at 0.45 MPa the competitor material datasheet reports 145 °C, which is less than that of Nylon-CF10 (153 °C) and greater than that of ABS-CF10 (117 °C). The competitor does not provide any performance data for HDT at 1.8 MPa, but Stratasys has tested the one material at the higher pressure for HDT. For that material, the HDT at 1.8 MPa was 71 °C, which is a 51% decrease in the HDT temperature from the lower pressure for that material. For ABS-CF10 and Nylon-CF10 there is only a 4% and 13% decrease in the HDT temperature with the higher pressure.

For impact strength, the competitor material is higher than ABS-CF10 and Nylon-CF10. By using the same test methodology, the values are more appropriate for the comparison to the competitor material.

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Comparison of Mechanical and Physical Properties between Stratasys Materials and Competitor Materials

	Material Property	ABS-CF10	Nylon-CF10	Competitor Material 1	Competitor Material 2
Tensile[2]	Modulus of Elasticity (GPa)[1]	5.22	6.03	2.4	3.0
	Yield Strength (MPa)	44.9	68.1	40	41
	Elongation at Yield (%)	1.2	4.0	not reported	not reported
	Stress at Break (MPa)	44.6	64.4	37	40
	Elongation at Break (%)	1.2	5.1	25	18
Flexural	Modulus of Elasticity (GPa)	4.96	6.96	3.0	3.6
	Flexural Strength at Break (%)	2.6	3.4	not reported	not reported
	Flexural Stress at Break (MPa)	89.3	138	71	71
HDT	Heat Deflection Temperature - 0.45 MPa (°C)	117	153	145	145
	Heat Deflection Temperature - 1.8 MPa (°C)	112	133	105 (Stratasys lab testing[3])	not reported
Impact	Izod Impact - notched (J/m)	79.2	272	330	not reported

Table 5-Comparison of Mechanical and Physical Properties between Stratasys Materials and Competitor Materials

Notes:

1. Tensile modulus for ABS-CF10 and Nylon-CF10 is calculated on the stress-strain values from 15% to 35% of the max load. The range for the tensile modulus calculation is not known for the competitor material.
2. ABS-CF10 and Nylon-CF10 samples were printed to shape with unidirectional toolpaths. Competitor material tensile coupons were cut to shape.
3. Competitor does not report the higher pressure of HDT testing. Following their methods and testing at Stratasys, this was the value noted for the 1.8 MPa. Stratasys measurements of the HDT at 0.45 MPa were very similar to their reported values.

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Conclusion

Because of the large influence that toolpaths have on mechanical and physical properties, customers of additive manufacturing companies need to look closely at what data is being presented to make accurate apple-to-apple comparisons between material properties.

By switching between 45°/-45° standard toolpaths and the optimized unidirectional toolpaths, we have shown drastic changes in the material performance of ABS-CF10 and Nylon-CF10. For HDT, Nylon-CF10 showed a 160% increase by changing the toolpaths at both 0.45 MPa and 1.8 MPa. For tensile strength, ABS-CF10 presented a 71% increase in the elastic modulus. Nylon-CF10 had a 152% increase in the elastic modulus and 94% in the yield strength with the unidirectional toolpaths. These are not minor changes to strength and ultimately part performance and make a drastic difference when comparing to competitor materials that are always tested with optimized unidirectional toolpaths. Mechanical testing, especially if being utilized for design limits, should be performed on specimens that are representative of part geometries. Optimizing toolpaths in the strongest orientation shows the maximum possible strength, but may not correspond to the actual part strength, and is not advised as the standard test methodology.

Appendix A - Software Versions, Test Equipment, and Calibration History

	ABS-CF10	Nylon-CF10
Processing software	Insight 16.10 (Build 4372)	
Software for packing builds	Control Center 16.10 (Build 4372)	
Printer S/N for builds	D80022	D80005
Printer backend software	2.5.5966.0	2.6.5976.0
Material information	PN: 333-90310 SN: 630755611 Mfg. Date: 04-Jun-2022 Lot: 112995	PN: 333-90450 SN: 676936711 Mfg. Date: 13-Apr-2023 Lot: 114590

Table 6 - Software Versions, Machine Information, and Material Information

Testing	Equipment	Serial Number	Calibration Date
Tensile Testing	MTS Criterion 43	5001678	6/15/2023
Tensile Load Cell	10kN Load Cell LPS-104C	1010933	6/16/2023
Extensometer	2 in Extensometer 634-28E-24	10574728	6/15/2023
Flex Testing	MTS Criterion 43	5000462	6/14/2023
Flex Load Cell	5kN Load Cell LPS-503C	1021979	6/14/2023
HDT	DMA Q300	0800-1786	3/29/2023
Impact Testing	Tinuis Olsen 892 Impact Tester	195795	1/31/2023

Table 7 - Test Equipment and Calibration Date

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Appendix B - Tables in Imperial Units

	HDT (°F)			
	ABS-CF10		Nylon-CF10	
Toolpaths	Low (66 psi)	High (264 psi)	Low (66 psi)	High (264 psi)
Unidirectional Toolpaths (XY orientation)	242	233	307	271
Standard 45/-45 Toolpaths (XY orientation)	234	233	136	126
As-Molded	212	210	228	221

Table 1 - HDT of ABS-CF10 and Nylon-CF10 (Imperial Units)

	ABS-CF10		Nylon-CF10	
Toolpaths	Unidirectional	Standard 45/-45	Unidirectional	Standard 45/-45
Modulus of Elasticity (ksi)	756	441	875	347
Yield Strength (psi)	6500	5200	9880	5100
Elongation at Yield (%)	1.2	3.0	4.0	5.6
Stress at Break (psi)	6470	5170	9330	3230
Elongation at Break (%)	1.2	3.0	5.1	8.2

Table 2 - Tensile Data of ABS-CF10 and Nylon-CF10 in the XY Orientation (Imperial Units)

Flexural Strength of XY Specimen with Unidirectional Toolpaths		
	ABS-CF10	Nylon-CF10
Modulus of Elasticity (ksi)	719	1010
Flexural Strain at Break (%)	2.6	3.4
Flexural Stress at Break (ksi)	13.0	20.0

Table 3 - Flexural Strength of ABS-CF10 and Nylon-CF10 in the XY Orientation with Unidirectional Toolpaths (Imperial Units)

Izod Impact Strength of ABS-CF10 and Nylon-CF10 (ft*lb/in)			
Print Orientation	Toolpaths	ABS-CF10	Nylon-CF10
Flat (XY)	Unidirectional	1.48	5.10
OnEdge (XZ)	Standard 45°/-45°	0.962	3.79
Upright (ZX)	Standard 45°/-45°	0.381	0.68

Table 4 - Izod Impact Strength Data (Imperial Units)

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	Material Property	ABS-CF10	Nylon-CF10	Competitor Material 1	Competitor Material 2
Tensile[2]	Modulus of Elasticity (ksi)[1]	756	875	348	435
	Yield Strength (psi)	6500	9880	5800	5950
	Elongation at Yield (%)	1.2	4.0	not reported	not reported
	Stress at Break (psi)	6470	9330	5370	5800
	Elongation at Break (%)	1.2	5.1	25	18
Flexural	Modulus of Elasticity (ksi)	719	1010	435	522
	Flexural Strength at Break (%)	2.6	3.4	not reported	not reported
	Flexural Stress at Break (psi)	13000	20000	10300	10300
HDT	Heat Deflection Temperature - 66 psi (°F)	243	307	293	293
	Heat Deflection Temperature - 264 psi (°F)	233	271	160 (Stratasys lab testing[3])	not reported
Impact	Izod Impact - notched (ft*lb/in)	1.48	5.10	6.18	not reported

Table 5-Comparison of Mechanical and Physical Properties between Stratasys Materials and Competitor Materials (Imperial Units)

Notes:
1. Tensile modulus for ABS-CF10 and Nylon-CF10 is calculated on the stress-strain values from 15% to 35% of the max load. The range for the tensile modulus calculation is not known for the competitor material.
2. ABS-CF10 and Nylon-CF10 samples were printed to shape with unidirectional toolpaths. Competitor material tensile coupons were cut to shape.
2. Competitor does not report the higher pressure of HDT testing. Following their methods and testing at Stratasys, this was the value noted for the 1.8 MPa. Stratasys measurements of the HDT at 0.45 MPa were very similar to their reported values.

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