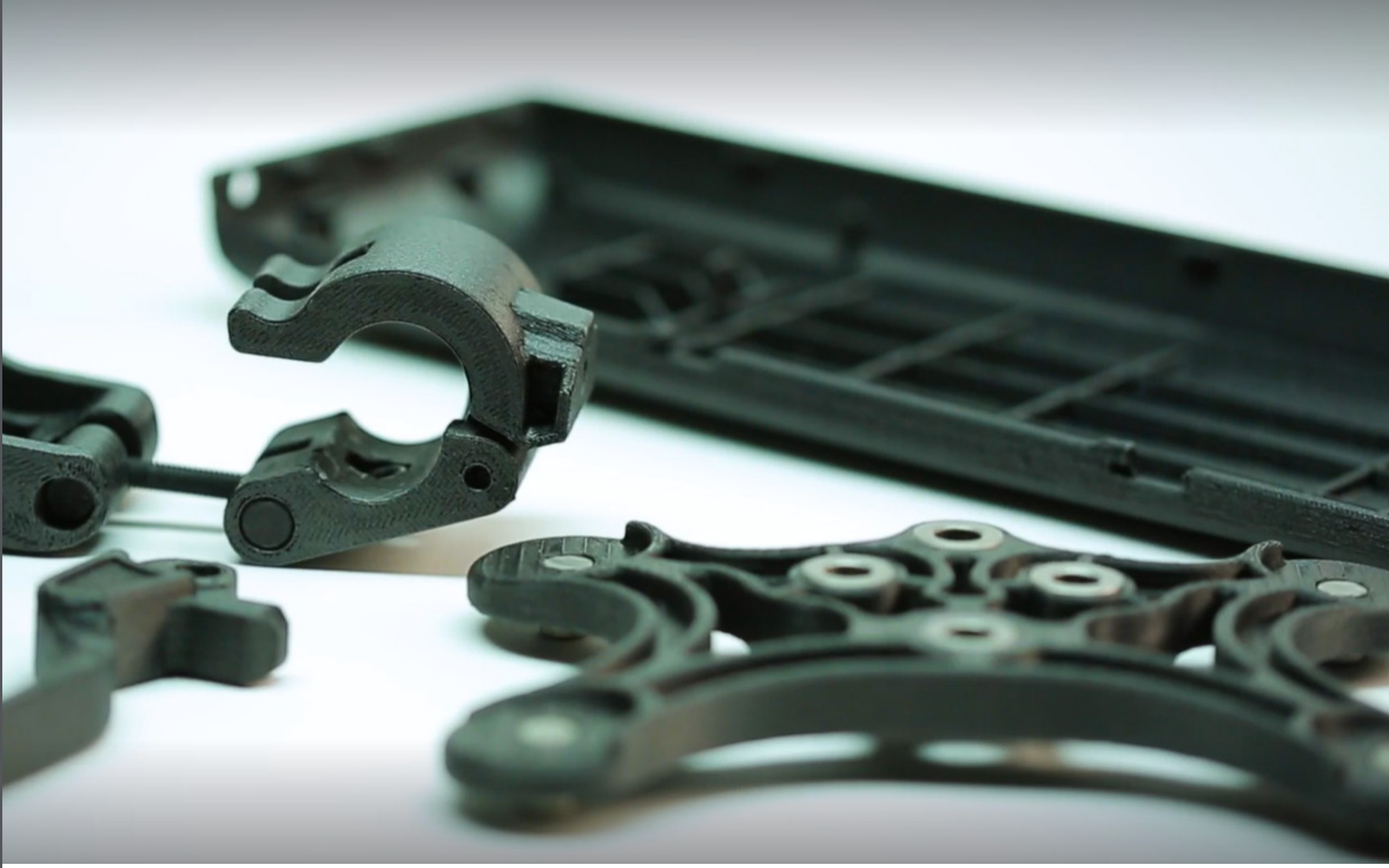


Comparison of Contiuous Carbon Fiber vs. Stratasys Nylon 12CF

Stiffness is really important when designing a component – how do you compare different additively manufactured materials or even different manufacturers.

In this white paper, we are comparing two types of additively manufactured Carbon fiber reinforced thermoplastic. Namely – Nylon 12CF from Stratasys which has 35% chopped carbon fiber and a competitor Nylon material with continuous carbon fibers.

How are we comparing such materials ? You may wonder.

By following the next simple steps:

- Print the same parts with both Nylon 12CF and Continuous Carbon Fiber
- Create a test bench
- Load the parts
- Measure the deflection

and finally you will find results which might surprise you.

Stratasys Nylon 12 Carbon Fiber is stiffer than Continuous Carbon Fiber.

Solution Brief

Two versions of the same part, a lever used to close a boat hatch, were identified for this experiment, one which is a very conservative design to be printed solid, and another part which is a lightweight truss style design to act as a more highly stressed part to explore the comparison in more detail.

Materials in Testing

The parts for the test were printed using as similar print settings as possible whilst comparing **Stratasys FDM® Nylon 12CF™** product to a **competitors continuous carbon fiber** product.

Stratasys Nylon 12CF™ is a PA12 (polyamide 12) thermoplastic filament combining Nylon 12 and chopped carbon fiber, 35% by weight, to achieve the highest flexural strength and stiffness-to-weight ratio of any FDM material. Nylon 12CF provides a cleaner carbon fiber additive process than SLA with equivalent strength properties.

FDM Nylon 12CF offers the strength and rigidity to replace metal components in certain applications. Replacing heavy aluminium or steel tools with carbon fiber FDM parts provide an opportunity for lighter, ergonomic and cheaper assemblies. In addition, FDM Carbon Fiber parts enable a faster design validation instead of costly and time-consuming metal prototypes.

The combination of high strength, stiffness and light weight makes it an optimal replacement for forming die, end of arm tools, grippers, soft jaws, lever, risers and much more. The durability of the thermoplastic make not only suitable for prototyping but also for end use parts.

Test Set Up

Two versions of the same part were identified for this experiment, one which is a very conservative design to be printed solid.

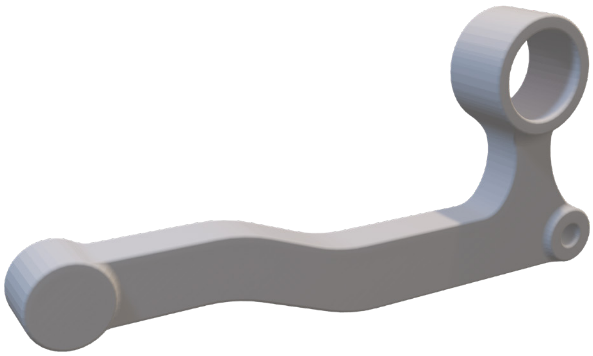


Figure 1: Part No 1, solid latche handle

And another part which is a lightweight truss style design to act as a more highly stressed part to explore the comparison in more detail. So both are real parts with bends and curves, not just straight dog bones.

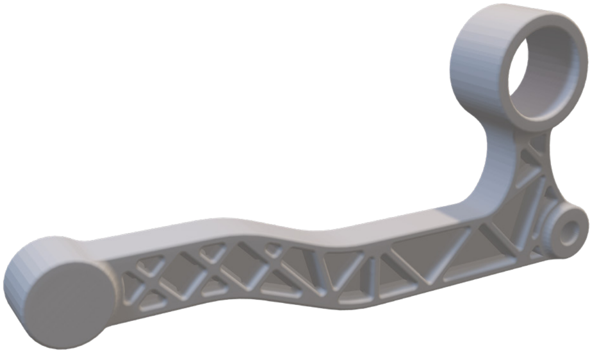


Figure 2: Part No 2, lightweight truss style design

Both parts are window latch handles from an ocean-going vessel and provide excellent examples of real-world geometries that need to be stiff in multiple directions. These parts were printed using as similar print settings as possible whilst comparing Stratasys chopped fiber Nylon12CF product to a competitor's continuous carbon fiber product.

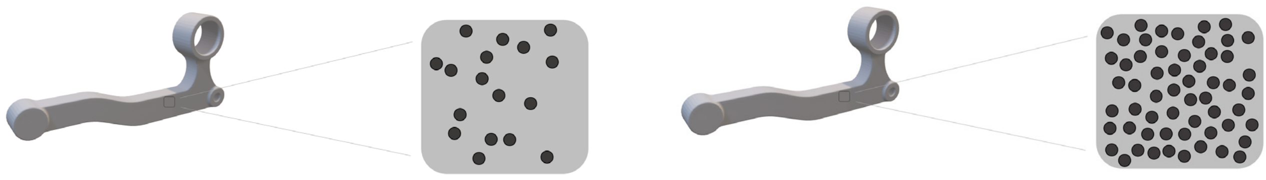
The parts were clamped down to a table (Figure 3) using a solid aluminium bar at one end then 1 to 30kg of weights were progressively added to the other. A digital dial indicator was used to measure the resulting deflection of the window latch handle as weights were added and this measurement was used to demonstrate the stiffness of the different parts (Figure 4).

Figure 3: Parts clamped to the table

Figure 4: Add metal weights and measure results with a dial indicator

Results & Discussion

To interpret the test results it might be helpful to have a look at the carbon fiber composites theory and why the results are so different.



Part Volume

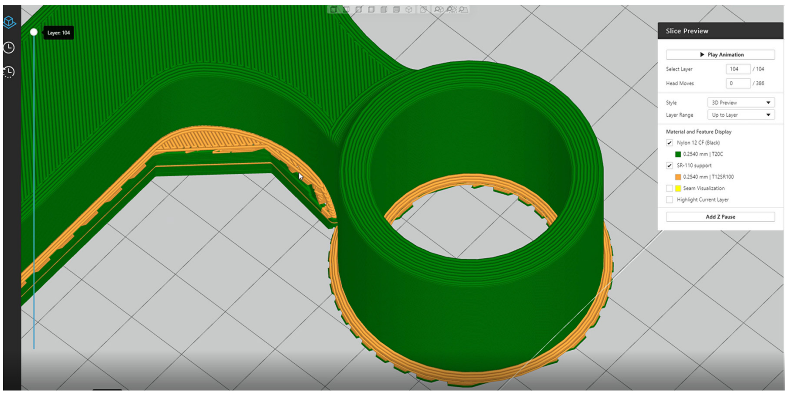
$$V = V_m + V_f \downarrow$$

Part Volume

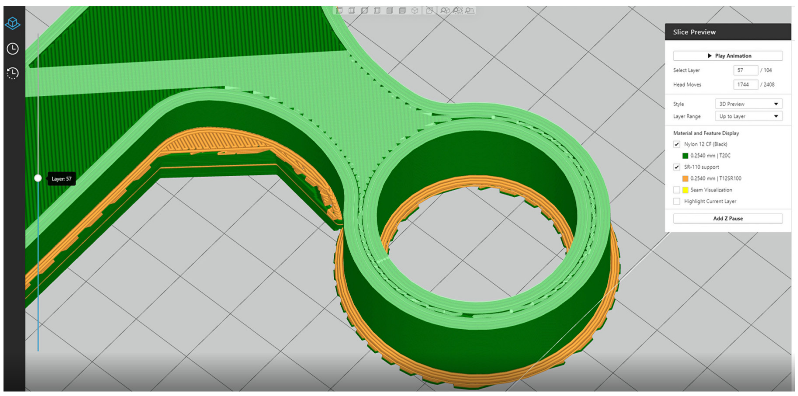
$$V = V_m + V_f \uparrow$$

One factor that has a significant impact on part stiffness is how many fibers are included in a part. After all the carbon fiber is around 170 times stiffer than the nylon matrix it is carried in, so less fibers less stiffness. But surely, a continuous carbon fiber would mean more fibers and a stiffer part. For traditional cloth based composites this is absolutely true but for additive manufacturing we need to consider a different approach.

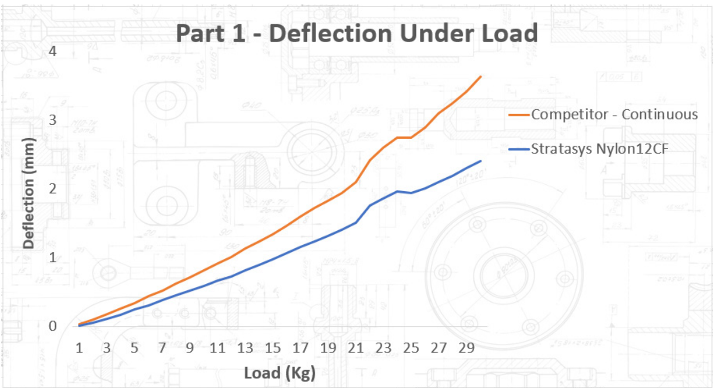
Zooming on to look at the toolpath we need for this bracket you will see the outer contours have to follow its shape. With continuous fibers it becomes very difficult to tightly pack them into these curved areas.

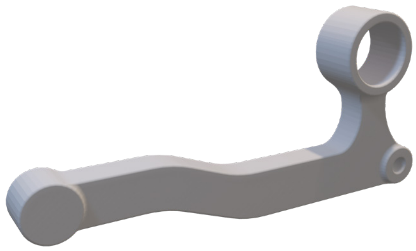


Extruded filaments with chopped fibers however can go right to the corners and we can vary extrusion thickness on the fly to help pack more in. The result is with short strand fibers you actually get a higher fiber fraction in your part and that's reflected in the results of our experiment.



Test Results Part 1 - Solid latch handle



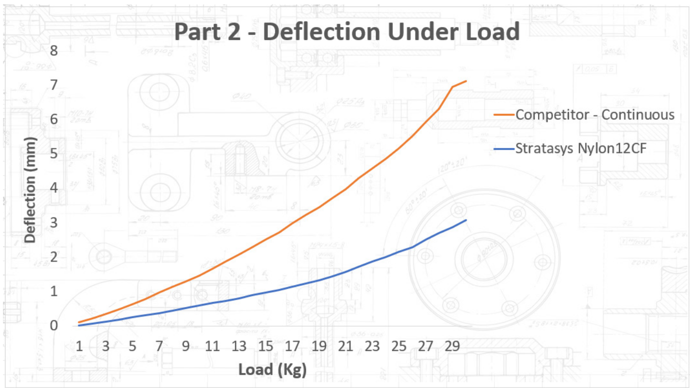


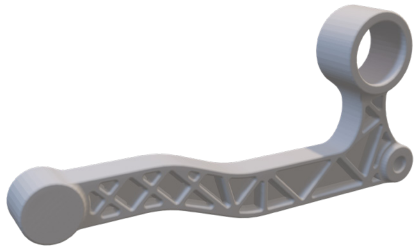
Test Sample	Weight (kg)	Deviation (mm)	Test Sample	Weight (kg)	Deviation (mm)
	1	0,01		1	0,03
	2	0,05		2	0,10
	3	0,11		3	0,18
	4	0,17		4	0,26
	5	0,25		5	0,34
	6	0,30		6	0,44
	7	0,38		7	0,52
	8	0,45		8	0,62
	9	0,52		9	0,71
	10	0,59		10	0,81
	11	0,66		11	0,92
	12	0,72		12	1,00
	13	0,81		13	1,13
	14	0,89		14	1,23
N12CF	15	0,97	CCF	15	1,34
	16	1,06		16	1,46
	17	1,15		17	1,59
	18	1,23		18	1,72
	19	1,31		19	1,82
	20	1,40		20	1,94
	21	1,50		21	2,09
	22	1,76		22	2,41
	23	1,86		23	2,59
	24	1,96		24	2,74
	25	1,94		25	2,74
	26	2,00		26	2,89
	27	2,10		27	3,10
	28	2,19		28	3,24
	29	2,30		29	3,41
	30	2,40		30	3,63

The Stratasys part, shown in blue, has a much lower deflection at the full load of 30kg coming in at around 2.4mm. The competitors part, shown in orange, however has a deflection of 3.6mm – 50% lower stiff despite the continuous fibers.

These parts were both printed solid in their respective software and with the continuous fiber, as many fibers as possible have been added to the part to have comparable parts. Of particular note is how the competitors line is beginning to become non-linear and that shows that the part is plastically deforming and yielding permantly much earlier in the test than the Stratasys part.

Test Results Part 2 - Lightweight truss style design



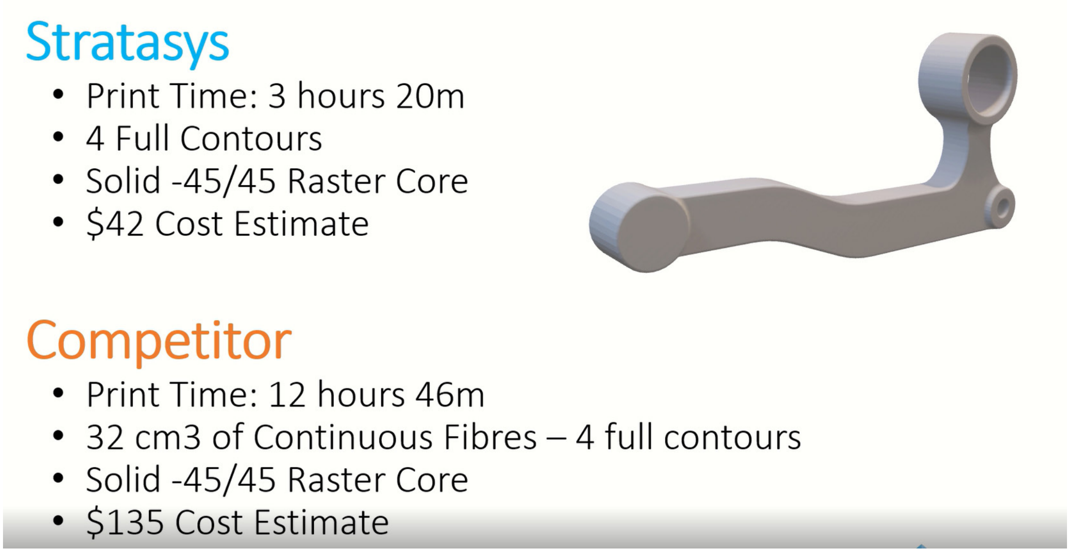


Test Sample	Weight (kg)	Deviation (mm)	Test Sample	Weight (kg)	Deviation (mm)
N12CF	1	0,02	CCF	1	0,10
	2	0,07		2	0,23
	3	0,13		3	0,35
	4	0,19		4	0,49
	5	0,25		5	0,64
	6	0,32		6	0,79
	7	0,38		7	0,97
	8	0,45		8	1,14
	9	0,52		9	1,29
	10	0,60		10	1,47
	11	0,67		11	1,67
	12	0,73		12	1,88
	13	0,81		13	2,09
	14	0,89		14	2,29
	15	0,97		15	2,51
	16	1,05		16	2,73
	17	1,14		17	2,99
	18	1,24		18	3,24
	19	1,34		19	3,46
	20	1,45		20	3,72
	21	1,57		21	3,99
	22	1,73		22	4,30
	23	1,88		23	4,58
	24	2,01		24	4,87
	25	2,16		25	5,17
	26	2,30		26	5,52
	27	2,51		27	5,94
	28	2,70		28	6,32
	29	2,88		29	6,96
	30	3,09		30	7,13

The lightweight truss style designed part is more challenging. Stratasys part, shown in blue, has a deflection of just 3.1mm at the full load of 30kg where as the competitor has a deflection of 7.1mm. This is more than double the deflection and the sharply rising orange curve shows us the competitor part is yielding plastically right from the beginning of the experiment. Again, this result occurs despite a high level of continuous carbon fibers.

Print Settings Part 1 - Solid latch handle

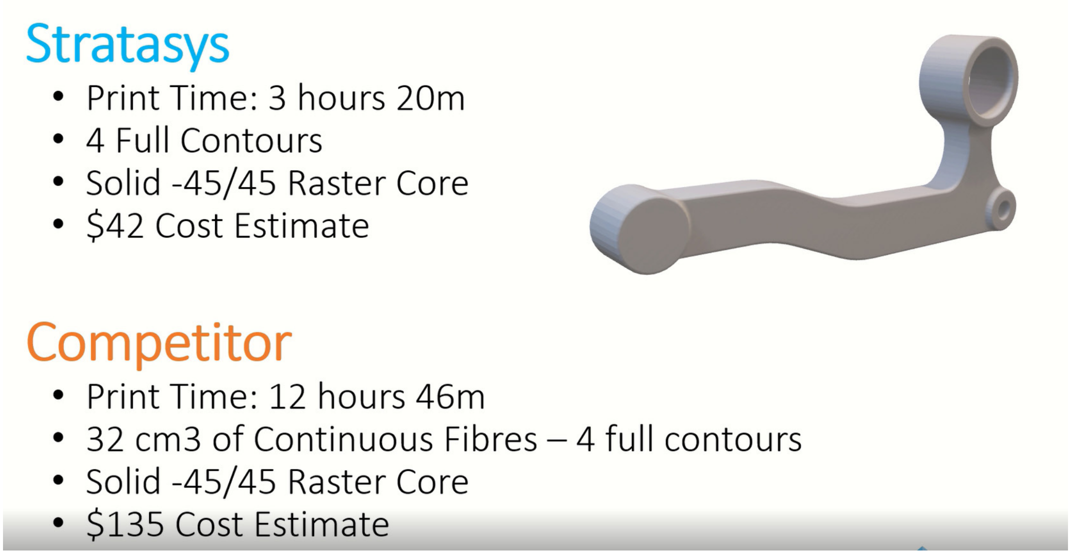
For the solid style handle both Stratasys and competitor parts had a full 4 outer contours and solid raster infill which is a like for like comparison.



The Stratasys part was 4 times faster to print and over 3 times cheaper and still came out significantly stiffer.

Print Settings Part 2 - Lightweight truss style design

For the trust style part comparable settings have been used for the Stratasys and the competitor versions. This time 3 contours and still solid raster infill.



The Stratasys was nearly 5 times faster due to the detail of printing the trust work and again 3 times cheaper in material cost for ultimately a stiffer part.

Conclusion

In all tests Stratasys

- Nylon12 CF was found to be significantly stiffer than the competitors product.
- The Stratasys part printed about 4 to 5 time faster while being 3 times cheaper.

An investigation into the theory of thermoplastic carbon fiber composites helped to understand why the results are different from what you might expect.

Fiber fraction of a composite material is the biggest contributor of the resulting composites stiffness. The competitors solution despite using continuous carbon fibers was unable to tightly pack them into the part and as a result the competitor's fiber fraction was lower resulting in lower stiffness.

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