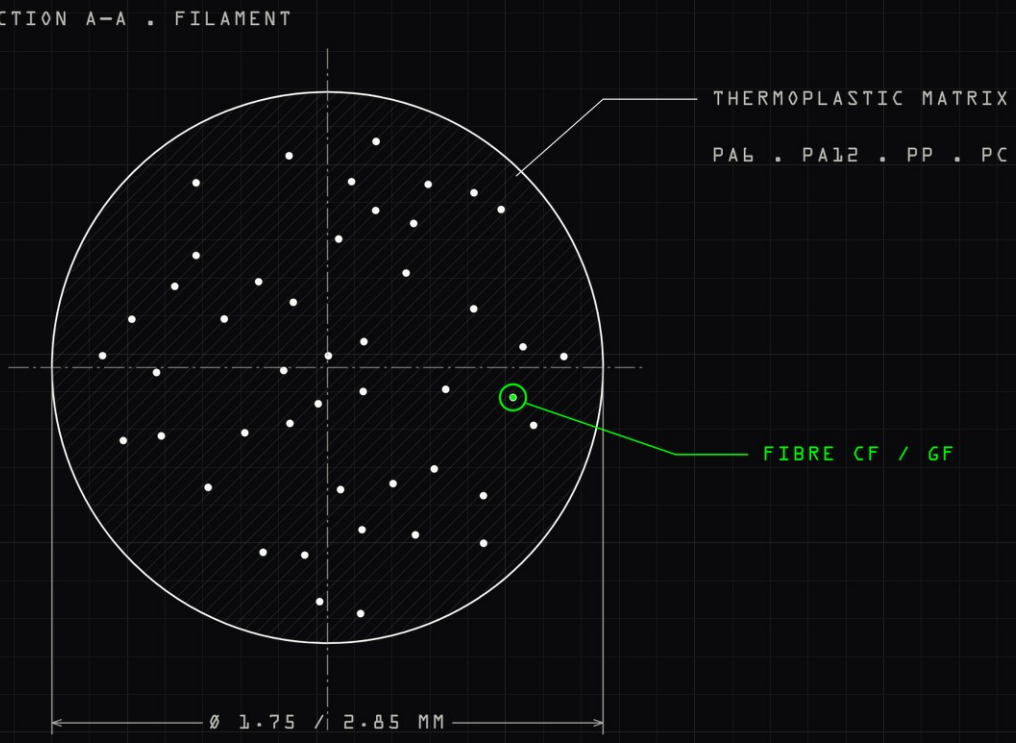
FIBERTHREE



WHITE PAPER . WP001

PLASTICS FOR THE FFF PROCESS

Which plastic suits which task, and when is FFF the right process compared with SLS and SLA/DLP?

DOCUMENT

WP001

FIBERTHREE WHITE PAPER

DATE

11.2026

VERSION 1.0

CONTENTS

01 Background 4

02 Printability basics 6

Amorphous or semi-crystalline 6

Moisture uptake 6

Warping and build chamber 6

03 Material overview 7

Why polyamide is at the centre 8

04 Fibre-reinforced and functional filaments 10

Carbon or glass 10

Functional filaments 10

05 Process comparison FFF, SLS, SLA/DLP 12

Which process when 13

06 Decision guide 14

07 Conclusion 15

References 15

About Fiberthree 16

White Paper Series 16

00 . EXECUTIVE SUMMARY

Today almost the full range of engineering thermoplastics is available for FFF printing, from PLA to PEEK. For technical functional parts, polyamide is the most versatile material: strong, tough, wear-resistant and resistant to oils and fuels. Reinforced with fibres, F3 PA-CF Pro reaches a tensile strength of 115.7 MPa and a modulus of 11,423 MPa along the bead (DLR).

Compared with SLS and SLA/DLP, FFF offers the widest choice of materials, fibre-reinforced materials and the lowest entry cost. In return, its anisotropy is the highest: up to about 50 %, compared with about 10 % for SLS and 1 to 5 % for SLA and DLP. SLS plays to its strengths with many small, complex parts, SLA and DLP with smooth, detailed surfaces.

A material overview, a process comparison and a decision table help with the choice.

AT A GLANCE

- **Polyamide** is the most versatile material for technical functional parts: strong, tough, wear-resistant and resistant to oils and fuels.
- **Fibres** turn a standard plastic into an engineering material: F3 PA-CF Pro reaches 115.7 MPa along the bead (DLR).
- **FFF** offers the widest choice of materials and the lowest entry cost, but the highest anisotropy.
- **SLS and SLA/DLP** play to their strengths with many small, complex parts and with smooth, detailed surfaces respectively.

Recommendation: Choose the material by temperature, load and medium, then the process. When in doubt, a test print helps.

115.7 MPa	up to 50 %	11,423 MPa
Tensile strength F3 PA-CF Pro along the bead, DLR	Anisotropy in FFF, SLS about 10 %	Modulus F3 PA-CF Pro along the bead, DLR

01 BACKGROUND

Choosing the plastic is the first design decision. It determines which temperatures, loads and media a part can withstand, and how much effort printing and post-processing will take.

In FFF printing (Fused Filament Fabrication), almost the full range of engineering thermoplastics is available today: from PLA for visual models and polyamides for functional parts to high-performance plastics such as PEEK. On top of that come fibre-reinforced and functional filaments, for example electrostatic dissipative or biocompatible ones.

According to ISO/ASTM 52900, FFF belongs to the process category material extrusion: the material is selectively dispensed through a nozzle. The main alternatives for plastic parts are laser sintering (SLS, powder bed fusion) and stereolithography or DLP (vat photopolymerisation). This paper gives an overview of the plastics and shows when FFF is the right process and when it is not.

The process goes back to S. Scott Crump, who filed a patent for it in 1989; the patent was granted in 1992. It became known under the trademarked name FDM (Fused Deposition Modeling). FFF is the manufacturer-neutral term; German guidelines also call it material extrusion.

WP001 opens our white paper series:

NO.	TOPIC	HELPS WITH
WP001	**Plastics for the FFF Process: Material Overview and Process Comparison (this paper)**	**Choosing material and process**
WP002	Effect of Moisture on Polymers in the FFF Process	Drying filament and keeping it dry
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TAB. 1 Overview of the Fiberthree white papers.

02 PRINTABILITY BASICS

For FFF printing, the injection-moulding data sheet values matter less than three properties that decide printability and part quality.

AMORPHOUS OR SEMI-CRYSTALLINE

- **Amorphous plastics** (PLA in most cases, PETG, ABS, ASA, PC, PEI) soften gradually over a wide temperature range. They shrink little on cooling, hardly warp and print well. Their service limit is the glass transition temperature Tg: above it they become soft.
- **Semi-crystalline plastics** (PA6, PA12, PP, PEEK, PPS) have a sharp melting point Tm. Crystals form on cooling, the material shrinks more and tends to warp. In return they remain dimensionally stable above Tg, are more chemically resistant and tougher. In FFF printing they often crystallise only incompletely, which can be compensated by annealing (WP003).

MOISTURE UPTAKE

Polyamides, PC and TPU absorb water from the air and must be dried before printing (WP002). PP absorbs practically no water, PLA, PETG and ABS only a little.

WARPING AND BUILD CHAMBER

The larger the gap between print temperature and chamber temperature and the stronger the shrinkage, the more likely parts are to warp. High-temperature plastics such as PEEK and PEI therefore need a heated build chamber. Fibres considerably reduce shrinkage along the bead and make difficult plastics such as PA and PP easy to print (WP004).

03 MATERIAL OVERVIEW

The table ranks the plastics relevant to FFF by increasing temperature resistance. The temperatures are typical guide values for unfilled grades. The technical data sheet of the respective filament always takes precedence.

Data sheet values, too, usually apply to injection-moulded or flat-printed specimens and are not always reached in the part. In one study, the modulus of printed ABS specimens was 1.12 GPa, compared with 1.7 to 2.1 GPa from the literature (Szykiedans and Credo 2016). The gap is largest in the build direction; WP009 shows how the process can narrow it.

PLASTIC	STRUCTURE	TG / TM	PRINT TEMPERATURE	MOISTURE	WARPING	TYPICAL APPLICATION	FIBERTHREE
PLA	amorphous to semi-crystalline	Tg approx. 60 °C	190–220 °C	low	very low	Visual models, prototypes, fixtures without heat load	F3 PLA GF
PETG	amorphous	Tg approx. 80 °C	230–250 °C	low	low	Housings, brackets, simple functional parts	–
ABS / ASA	amorphous	Tg approx. 100–105 °C	240–260 °C	low	medium to high	Housings, exterior parts (ASA UV-resistant)	–
TPU	thermoplastic elastomer	–	210–240 °C	medium	low	Seals, dampers, grips	F3 TPU 80A, F3 TPU 98A
PP	semi-crystalline	Tg below 0 °C, Tm approx. 160–165 °C	220–240 °C	none	high, low with glass fibre	Media-resistant parts, containers, living hinges	F3 PP GF 25
PA12	semi-crystalline	Tg approx. 40–50 °C, Tm approx. 178 °C	260–300 °C	medium	medium	Functional parts with high dimensional stability	F3 PA Pure Lite, F3 PA-CF Lite

PLASTIC	STRUCTURE	TG / TM	PRINT TEMPERATURE	MOISTURE	WARPING	TYPICAL APPLICATION	FIBERTHREE
PA6	semi-crystalline	Tg approx. 50–75 °C (dry), Tm approx. 220–235 °C	260–300 °C	high	high, very low with fibres	Highly loaded functional and series parts, fixtures	F3 PA Pure Pro, F3 PA-CF Pro, F3 PA-GF Pro, F3 PA-GF30 Pro, F3 PA ESD, F3 PA Ortho
PC	amorphous	Tg approx. 145–150 °C	260–300 °C	medium	medium	Heat-resistant, stiff parts	F3 PC CF 150
PPS	semi-crystalline	Tg approx. 90 °C, Tm approx. 280 °C	300–340 °C	very low	medium	Parts under high chemical load, electrical engineering	–
PEI	amorphous	Tg approx. 215 °C	350–390 °C	medium	medium, heated chamber required	Aerospace, flame-retardant parts	–
PEEK / PEKK	semi-crystalline	Tg approx. 143 °C, Tm approx. 343 °C (PEEK)	370–420 °C	low	high, heated chamber required	Medical technology, aerospace, high temperature	–

TAB. 2 Plastics relevant to FFF, typical guide values for unfilled grades.

For printed F3 PA Pure Pro, the University of the Bundeswehr Munich measured a glass transition of about 75 °C and a melting peak of about 235 °C [Klingenbeck et al. 2026].

WHY POLYAMIDE IS AT THE CENTRE

Polyamide combines strength, toughness, wear resistance and resistance to oils, greases and fuels. This makes it the material for most technical functional parts. Its weaknesses in FFF printing, moisture

uptake and warping, can be controlled with drying (WP002) and fibre reinforcement. That is why polyamides form the core of our portfolio.

The three properties are connected. A semi-crystalline, moisture-sensitive plastic such as PA6 requires dry filament, a build plate with good adhesion and often a warm build chamber. In return it rewards you with toughness and resistance that amorphous standard plastics do not reach. Knowing these connections makes it possible to plan the printing effort realistically from the start.

04 FIBRE-REINFORCED AND FUNCTIONAL FILAMENTS

Short carbon or glass fibres turn a standard plastic into an engineering material. They align along the bead during extrusion and considerably increase stiffness and strength in that direction.

DLR measured this for the Fiberthree polyamides. Conditioned specimens along the bead reached the following values:

FILAMENT	FIBRE CONTENT	TENSILE STRENGTH 0°	MODULUS 0°
F3 PA PURE PR0	unfilled	67.5 MPa	2,853 MPa
F3 PA-GF PR0	15 % glass	79.5 MPa	4,565 MPa
F3 PA-GF30 PR0	30 % glass	98.2 MPa	7,001 MPa
F3 PA-CF PR0	15 % carbon	115.7 MPa	11,423 MPa

TAB. 3 DLR tensile tests on conditioned specimens along the bead.

Across the bead and in the build direction, little of this gain remains. WP004 describes how to design parts accordingly.

CARBON OR GLASS

	CARBON FIBRE (CF)	GLASS FIBRE (GF)
Stiffness	very high	high
Weight	low density	higher density
Surface	matt black	matt, can be coloured
Electrical	conductive, not insulating	insulating
Compressive strength	high	very high at 30 %
Cost	higher	lower

TAB. 4 Carbon and glass fibre compared.

Both fibres are abrasive and need a wear-resistant nozzle (WP006).

FUNCTIONAL FILAMENTS

- **Electrostatic dissipative:** F3 PA ESD discharges electrostatic charges in a controlled way, for example for fixtures in electronics manufacturing (WP008).
- **Biocompatible and transparent:** F3 PA Ortho passes the cytotoxicity test to ISO 10993-5 and is colourless and translucent.
- **Media-resistant without water uptake:** F3 PP GF 25 for parts that come into contact with water, acids or oils.

For most functional parts, three columns of the table are enough: how warm does the part get in use, which media does it come into contact with, and how much warping does the geometry tolerate? Only then is it worth comparing individual filaments in the technical data sheet.

05 PROCESS COMPARISON FFF, SLS, SLA/DLP

FFF is not the best process in every discipline, but it is the most versatile. It offers the widest choice of materials, is the only one of the three processes with fibre-reinforced materials across the full range, and has the lowest entry cost. In return, its anisotropy is the highest.

CRITERION	FFF (MATERIAL EXTRUSION)	SLS (POWDER BED FUSION)	SLA / DLP (PHOTOPOLYMERISATION)
Feedstock	thermoplastic filament	thermoplastic powder	liquid photopolymer (resin)
Choice of materials	very wide: PLA to PEEK, fibre-reinforced, ESD, elastomers	mainly PA12 and PA11, also PP, TPU, filled PA	resins with plastic-like properties, thermosets
Mechanical anisotropy	highest, up to about 50 %	about 10 %	DLP about 5 %, SLA about 1 %
Surface	visible layers	rough, grainy	very smooth
Fine details	limited by nozzle diameter	good	very good
Support structures	needed from about 45° overhang	not needed, powder supports	needed
Post-processing	remove supports, optionally anneal	depowdering, blasting	washing, UV post-curing, remove supports
Long-term behaviour	like the thermoplastic	like the thermoplastic	resins age under UV and can embrittle
Equipment cost	low	high	low to medium
Economical for	single parts to small series, large parts	many small parts in one build	small, detailed parts

TAB. 5 FFF, SLS and SLA/DLP compared. Anisotropy after Zohdi and Yang 2021, see also Kafle et al. 2021.

WHICH PROCESS WHEN

- **FFF** when a specific material is required (fibre-reinforced, PP, PC, ESD), when stiffness in one direction counts, for large parts and for single parts or small series with short lead times.
- **SLS** when many small parts with complex geometry are needed without supports and the properties should be as equal as possible in all directions.
- **SLA / DLP** when surface and detail accuracy come first, for example for appearance models, mould inserts or dental applications, and the long-term load is low.

The values show the potential of the fibres along the bead. Whether it reaches the part is decided by the design: only if the beads run along the load does the fibre contribute. Fibre-reinforced filaments are therefore no substitute for design for manufacturing; they pay off precisely when part and bead path are matched to each other.

When choosing between carbon and glass, the application helps: if stiffness and weight count, carbon has the edge. If electrical insulation, compressive strength or cost count, glass is often the better choice.

FIG. 1: SCHEMATIC SECTION A–A . FILAMENT

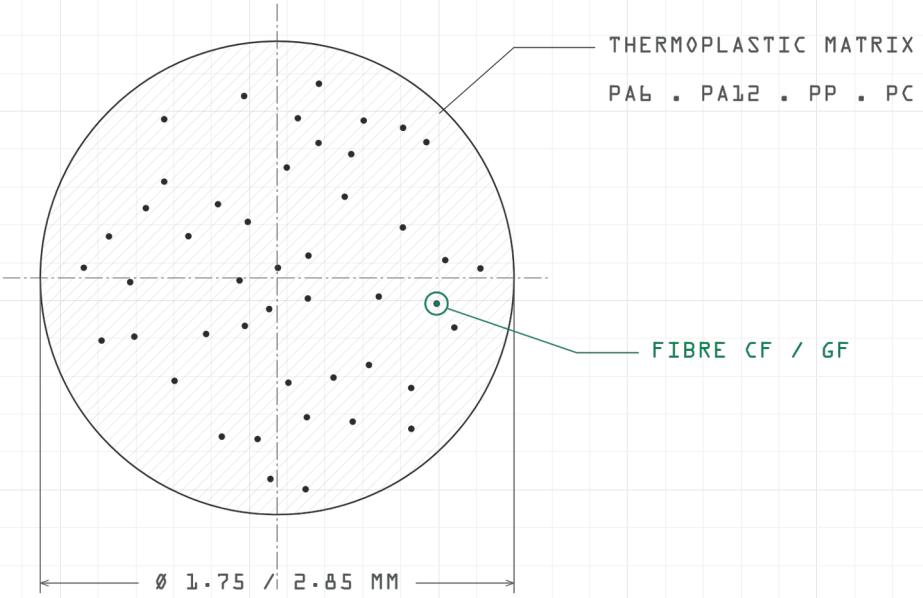


FIG. 1 Filament cross-section with thermoplastic matrix and short fibres, schematic, not to scale.

06 DECISION GUIDE

REQUIREMENT	RECOMMENDED MATERIAL	PROCESS
Maximum stiffness at low weight	F3 PA-CF Pro	FFF
High compressive strength, cost-effective	F3 PA-GF30 Pro	FFF
Tough, impact-resistant, snap fits	F3 PA Pure Pro, F3 PA Pure Lite	FFF or SLS
Dimensionally stable under changing humidity	F3 PA-CF Lite (PA12)	FFF or SLS
Continuously above 100 °C	F3 PC CF 150, annealed PA6	FFF
Contact with water, acids, oils	F3 PP GF 25	FFF
Electrostatic dissipative	F3 PA ESD	FFF
Biocompatible, transparent	F3 PA Ortho	FFF
Elastic, damping	F3 TPU 80A, F3 TPU 98A	FFF or SLS
Visual model with smooth surface	resin	SLA / DLP
Many small, complex parts, isotropic	PA12 powder	SLS

TAB. 6 Decision guide for material and process.

When in doubt, a test print helps. Our engineering team advises on material selection and prints first samples on more than 30 printers.

The processes do not exclude each other. In many projects, appearance models are made by resin printing, small series parts by laser sintering, and fixtures, large parts or fibre-reinforced functional parts by FFF printing. What matters is knowing, for each part, the requirement that determines it most.

A particular strength of FFF is that material and process can be chosen together: with a suitable filament, properties can be set that the other processes only offer through a few standard materials.

07 CONCLUSION

For technical functional parts, polyamide is the most versatile material in FFF printing. Its weaknesses, moisture uptake and warping, can be controlled with drying and fibre reinforcement. FFF offers the widest choice of materials and the lowest entry cost; SLS and SLA/DLP are the better choice when many small, isotropic parts or smooth, detailed surfaces are needed.

The decision guide in Chapter 06 sums up the most common requirements. The other white papers in the series go deeper into the steps that follow: drying, post-processing, design and the choice of nozzle and print bed.

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ABOUT FIBERTHREE

Fiberthree develops and produces technical filaments for FFF printing in Darmstadt, with polyamide at the heart of the portfolio. Building on our background as an engineering office, we also offer engineering, training and contract manufacturing on more than 30 printers, from first sample to small series.

WHITE PAPER SERIES

All white papers are available at www.fiberthree.com. We update the series regularly; the latest version applies.

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TAB. 7 Overview of the Fiberthree white papers.

FIBERTHREE

START WITH THE RIGHT MATERIAL

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