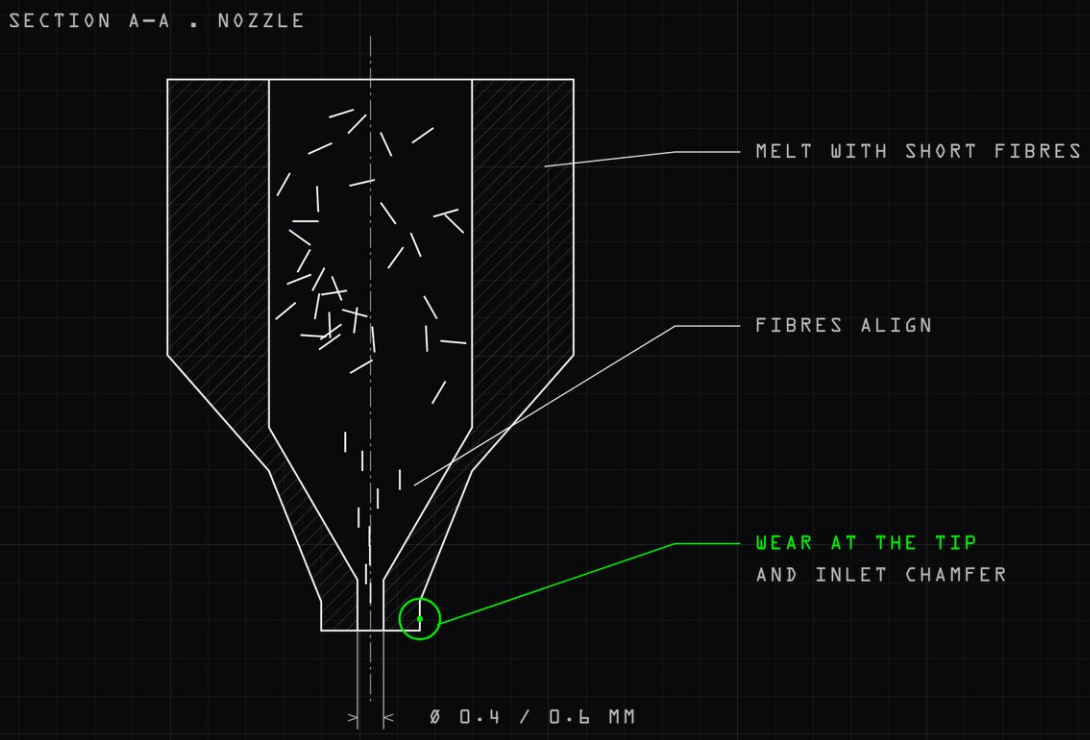
FIBERTHREE



WHITE PAPER . WP006

NOZZLE SELECTION FILLED FILAMENTS

Which nozzle material and which diameter suit carbon- and glass-fibre-reinforced filaments?

DOCUMENT

WP006

FIBERTHREE WHITE PAPER

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00 . EXECUTIVE SUMMARY

Carbon and glass fibres wear down brass nozzles in a short time. A study with fibre-reinforced PA6 shows what this costs: after about 92 hours of printing on a nickel-plated brass nozzle, the tensile strength of the printed specimens dropped by 37 % and the modulus from about 10.3 to 6.3 GPa.

AT A GLANCE

- **Material:** for filled filaments at least hardened steel, for high consumption tungsten carbide or a composite nozzle with a hard insert. Brass only for unfilled filaments.
- **Temperature:** print 5 to 15 °C hotter with steel nozzles, because steel conducts heat less well.
- **Diameter:** 0.4 mm as a minimum, 0.6 mm for functional parts. Larger nozzles clog less often and usually give stronger parts, smaller ones are more dimensionally accurate.
- **Monitoring:** measure the bead width of a reference part and change nozzles before part quality drops.

Recommendation: For filled filaments use at least hardened steel, tungsten carbide for high consumption, and measure wear regularly.

− 37 %	6.3 GPa	0.6 mm
Tensile strength after approx. 92 h on brass	Modulus afterwards, before 10.3 GPa	Diameter for functional parts

01 BACKGROUND

The nozzle is the component in the printer that touches every fibre. With unfilled filaments a brass nozzle lasts for many kilograms. Carbon and glass fibres, by contrast, act like an abrasive: they wear down soft nozzles in a short time and change their geometry, and with it the dimensional accuracy, surface and strength of the parts.

Two decisions have to be made for filled filaments:

- **The nozzle material** determines how long the nozzle keeps its geometry.
- **The nozzle diameter** determines whether the fibres pass through reliably, how fine details become and how strong the part will be.

This paper describes both and gives recommendations for the fibre-reinforced Fiberthree filaments.

The chapters start with the wear itself, then compare the nozzle materials and the diameter, give recommendations for each fibre-reinforced Fiberthree filament and close with notes on changing, care and clogging.

FIG. 1: SCHEMATIC

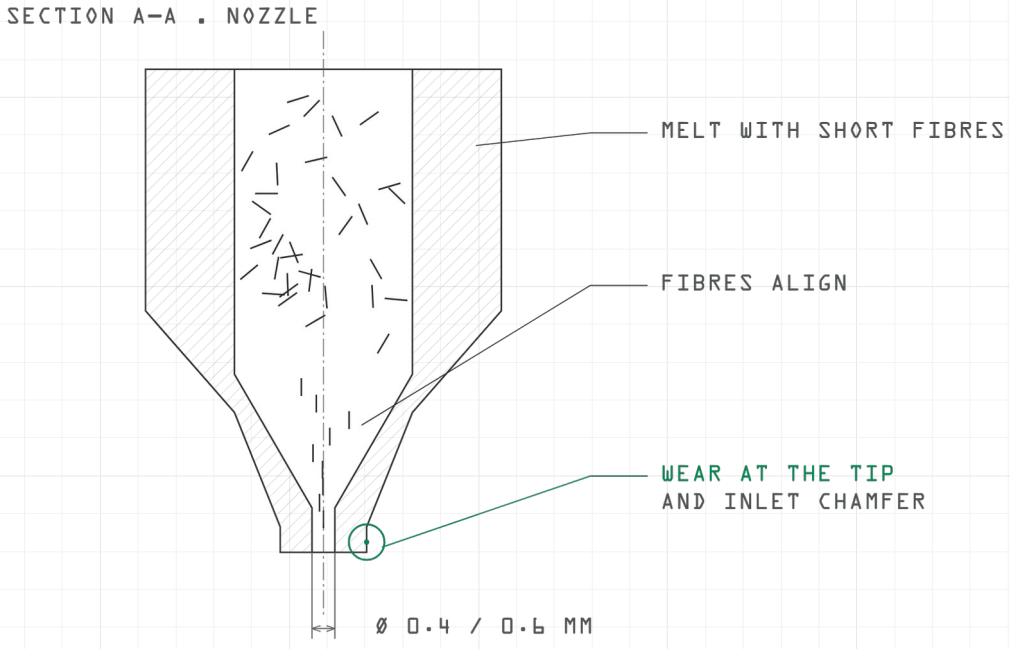


FIG. 1 Nozzle in section with aligning short fibres, schematic, not to scale.

02 WEAR CAUSED BY FIBRES

During extrusion the fibres slide along the nozzle wall with the melt and wear it away. The areas most affected are those with the highest flow velocity and the closest contact: the chamfer at the inlet of the bore and the nozzle tip, which also brushes over the printed surface.

WHAT RESEARCH SHOWS

In 2024 Bianchi et al. ran a nickel-plated 0.4 mm brass nozzle for more than 90 hours with a PA6 containing 20 % short carbon fibres and printed tensile specimens at intervals [Bianchi et al. 2024]:

MEASURED VALUE	NEW NOZZLE	AFTER APPROX. 92 H (5,540 MIN)
Tensile strength	122.3 MPa	76.7 MPa (– 37 %)
Modulus	approx. 10.3 GPa	approx. 6.3 GPa
Elongation at break	1.9 %	3.4 %
Roughness Ra of the nozzle	1.7 µm	14.1 µm

TAB. 1 Effect of nozzle wear on printed specimens of PA6 with 20 % short carbon fibres, after Bianchi et al. 2024.

In the first 15 hours the strength dropped by only about 7 %, after that considerably faster. The wear was mainly at the tip and at the inlet chamfer. The consequences in the part were more pores, uneven bead widths and poorer fibre alignment.

HOW TO RECOGNISE A WORN NOZZLE

- Beads become wider or uneven, dimensions grow.
- The surface becomes rougher, the nozzle tip leaves grooves.
- The tip is rounded instead of flat, the outlet no longer circular.
- Under- or over-extrusion although flow and temperature are unchanged.

Even a slightly worn nozzle therefore costs strength long before it is visibly damaged.

03 NOZZLE MATERIALS COMPARED

A nozzle for filled filaments must be considerably harder than the fibres and should still transfer heat well. Only tungsten carbide and composite nozzles with a hard insert offer both at the same time.

MATERIAL	HARDNESS (APPROX.)	THERMAL CONDUCTIVITY	SUITABILITY FOR CF/GF	NOTES
Brass	100–150 HV	very good	not suitable	Standard for unfilled filaments. Noticeably worn with fibres after only a few hundred grams
Brass, nickel-plated / coated	base body like brass	very good	not suitable	The coating improves release, not wear resistance
Stainless steel	approx. 200 HV	low	limited	Intended for food contact, also wears with fibres
Hardened tool steel	approx. 600–700 HV	low	good	Inexpensive standard for filled filaments. Raise the temperature slightly
Tungsten carbide	approx. 1,500–1,800 HV	good	very good	Very wear-resistant with good heat transfer. Our recommendation for heavy users
Brass or copper with ruby or carbide insert	insert approx. 2,000 HV	good	very good	Hard insert only at the tip. Make sure the melt channel has no steps
Diamond (PCD)	over 8,000 HV	good	very good	Practically wear-free, expensive

TAB. 2 Nozzle materials compared.

The hardness values are typical orders of magnitude for the materials. They differ depending on manufacturer and heat treatment.

MIND THE THERMAL CONDUCTIVITY

Steel conducts heat considerably less well than brass. At the same set temperature the melt arrives colder at the tip, especially at high throughput. With a hardened steel nozzle, therefore raise the nozzle temperature by 5 to 15 °C or print more slowly. Tungsten carbide and composite nozzles usually need no correction.

A simple consideration is usually enough for the choice: how much filled filament is printed, and how important is consistent part quality over a long time? Occasional fibre-reinforced printing works well with hardened steel. Regular or series printing saves nozzle changes and rework with tungsten carbide or a composite nozzle.

With every material a smooth melt channel without steps is important. Edges and steps inside the nozzle promote deposits and clogging, regardless of hardness.

04 THE RIGHT DIAMETER

Larger nozzles are almost always the better choice for filled filaments. They clog less often, print faster and usually give stronger parts. Small nozzles are only worthwhile when fine details or high dimensional accuracy are required.

CLOGGING

The fibres have to pass the narrowest cross-section of the nozzle without jamming. Simulations show that the risk of clogging increases with fibre length and fibre content [Zhang et al. 2021]. With short fibres, a lower melt viscosity, i.e. a slightly higher temperature, helps. With long fibres only a larger diameter helps.

STRENGTH AND ACCURACY

Chacón et al. printed short-carbon-fibre-reinforced polyamide with different nozzle diameters [Chacón et al. 2021]:

- **Larger nozzles** tended to increase the mechanical properties and reduced manufacturing costs through shorter print times.
- **Smaller nozzles** gave higher dimensional accuracy.
- **Surface roughness and flatness** depended only weakly on the diameter.

Bianchi et al. also recommend considering larger nozzles after their wear tests [Bianchi et al. 2024].

RULES OF THUMB

NOZZLE	USE WITH FILLED FILAMENTS
0.25–0.3 mm	only for fine details if the data sheet allows. Increased risk of clogging
0.4 mm	standard for parts with details, minimum size for most CF/GF filaments
0.6 mm	recommended for functional parts: reliable flow, higher strength, shorter print time
0.8 mm and larger	large, solid parts, fixtures. Details and threads become coarse

TAB. 3 Rules of thumb for the nozzle diameter with filled filaments.

A sensible layer height is 40 to 70 % of the nozzle diameter. With filled filaments, layers that are too thin increase the back pressure and the risk of clogging.

A large diameter also pays off for the strength between the layers: for PLA it increased with the larger nozzle at the same layer height, and the advantage grew with layer height. Over the full range of layer heights it changed by a factor of about 3.5 (Kuznetsov et al. 2018). WP009 shows how temperature and speed come into play.

In practice it has proven useful to start with 0.6 mm as the standard for fibre-reinforced functional parts and only go smaller when details or dimensional accuracy require it. Layer height and line width should always match the diameter.

When changing the nozzle, check wall thicknesses and details in CAD, because a larger nozzle lays down wider beads.

05 RECOMMENDATIONS BY FILAMENT

FILAMENT	FILLER	NOZZLE MATERIAL	DIAMETER
F3 PA-CF PRO	15 % carbon fibre	hardened steel, better tungsten carbide	0.4–0.6 mm, from 0.25 mm possible according to data sheet
F3 PA-GF PRO	15 % glass fibre	hardened steel or tungsten carbide	0.4–0.6 mm
F3 PA-GF30 PRO	30 % glass fibre	tungsten carbide or composite nozzle with hard insert	0.6 mm, data sheet specimens printed with 0.6 mm
F3 PA-CF LITE	15 % carbon fibre	hardened steel, better tungsten carbide	0.4–0.6 mm
F3 PC CF 150	carbon fibre	hardened steel or tungsten carbide	0.4–0.6 mm
F3 PP GF 25	25 % glass fibre	hardened steel or tungsten carbide	from 0.4 mm according to data sheet
F3 PLA GF	glass fibre	hardened steel	from 0.4 mm
F3 PA ESD	conductively modified	hardened steel recommended	0.4 mm
F3 PA PURE PRO, F3 PA PURE LITE, F3 PA ORTHO	unfilled	brass is sufficient	from 0.2–0.25 mm according to data sheet
F3 TPU 80A, F3 TPU 98A	unfilled	brass is sufficient	0.4 mm and larger

TAB. 4 Nozzle recommendation by Fiberthree filament.

If you alternate between filled and unfilled filaments, a tungsten carbide or composite nozzle is the simplest option. It suits both without changing the nozzle.

06 CHANGING, CARE, CLOGGING

CHANGING THE NOZZLE

- Always change it hot and tighten it to the torque specified by the manufacturer. With nozzles changed cold, melt otherwise leaks at the thread.
- After the change, check flow and temperature on a test part, especially when changing from brass to steel.

MONITORING WEAR

- Regularly measure the bead width or wall thickness of a reference part. If it gets wider, the nozzle is worn.
- Document print time or printed quantity per nozzle. This makes it possible to set a change interval before part quality suffers.
- Do not reuse brass nozzles that have been used with filled filaments.

AVOIDING AND CLEARING CLOGS

- **Dry filament:** moisture impairs flow and leads to deposits (WP002).
- **No layers that are too thin** and no nozzles that are too small (Chapter 04).
- **Do not leave the nozzle at temperature for long** without extruding. The melt degrades and deposits in the nozzle.
- **Cold or hot pull:** insert filament at a slightly lowered temperature and pull it out. Unfilled polyamide such as F3 PA Pure Pro is well suited for this thanks to its toughness.
- **No soft steel needles** in hard insert nozzles. The insert can be damaged.

07 CONCLUSION

Carbon and glass fibres wear down soft nozzles, and even a slightly worn nozzle costs strength long before it is visibly damaged. For filled filaments, a wear-resistant nozzle therefore belongs in the printer, and the diameter should be chosen larger rather than smaller. Monitoring the bead width of a reference part lets you change the nozzle before the parts suffer.

The recommendations for each filament in Chapter 05 are a good starting point. For your own application, a test print with the chosen diameter is worthwhile before a series starts.

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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.

NO.	TOPIC	HELPS WITH
WP001	Plastics for the FFF Process: Material Overview and Process Comparison	Choosing material and process
WP002	Effect of Moisture on Polymers in the FFF Process	Drying filament and keeping it dry
WP003	Annealing and Post-Processing of FFF Parts	Annealing, conditioning, finishing
WP004	Design for Manufacturing in the FFF Process	Designing parts for FFF
WP005	Heat-Setting Threaded Inserts in FFF Parts	Detachable screw connections
WP006	**Nozzle Selection for Filled Filaments (this paper)**	**Nozzle material and diameter**
WP007	Print Bed and Adhesion	First-layer adhesion
WP008	Electrostatic Dissipative (ESD) Parts in FFF Printing	Printing and testing ESD parts
WP009	Interlayer Adhesion in the Build Direction: Nozzle Temperature, Print Speed and Hotend	Strength in the z direction

TAB. 5 Overview of the Fiberthree white papers.

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START WITH THE RIGHT MATERIAL

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