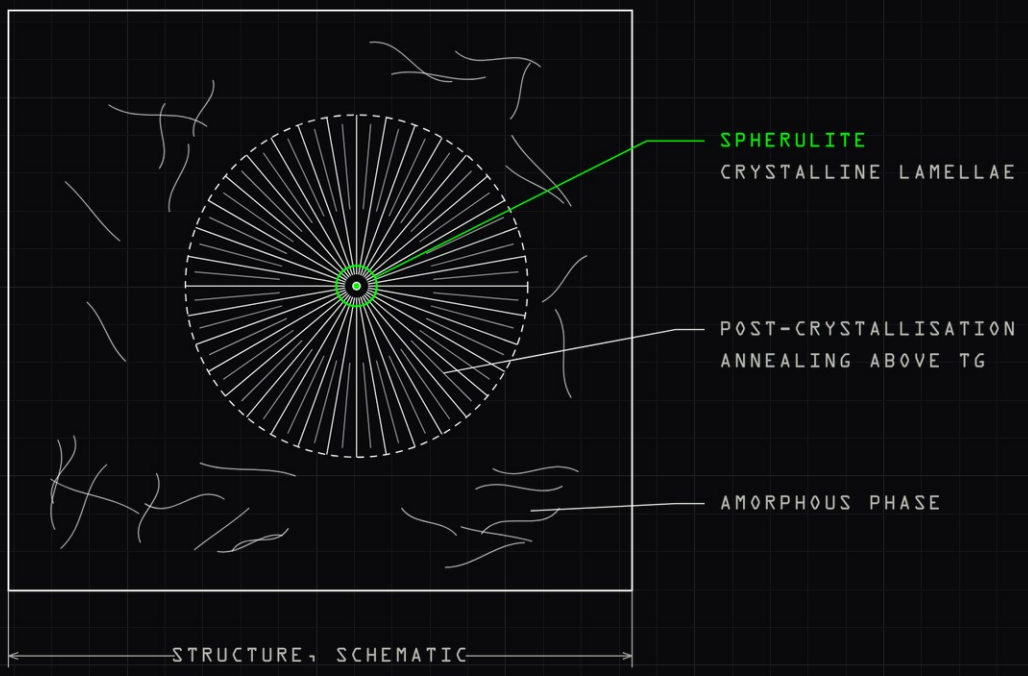
FIBERTHREE

DETAIL A . STRUCTURE AFTER ANNEALING



WHITE PAPER . WP003

ANNEALING AND POST-PROCESSING

How are polyamide FFF parts annealed, conditioned and finished after printing so that they reach their data sheet values?

DOCUMENT
WP003
FIBERTHREE WHITE PAPER

DATE
11.2026
VERSION 1.0

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00 . EXECUTIVE SUMMARY

Polyamide FFF parts leave the printer with low crystallinity and frozen-in stresses. Annealing completes the crystallisation, relieves stresses and makes the properties reproducible.

DLR measurements on F3 PA-CF Pro show: as printed, the degree of crystallinity lies between 17.8 and 28.7 % depending on the printer and the position in the part. After 24 hours at 75 °C all specimens reach 30.1 to 30.8 %. A drying oven is enough for this, and following WP002 it is already there for the filament.

This paper gives temperatures and holding times for all Fiberthree material families and describes how to allow for shrinkage. It also shows why polyamide should be conditioned after annealing. In addition it covers threaded inserts, machining and surfaces and sums everything up in a process sequence.

AT A GLANCE

- **Annealing** completes the crystallisation, relieves stresses and makes the properties reproducible.
- **F3 PA-CF Pro:** 17.8 to 28.7 % crystallinity as printed, 30.1 to 30.8 % after 24 hours at 75 °C (DLR).
- **A drying oven is enough,** and following WP002 it is already there for the filament.
- **Conditioning** after annealing sets the toughness of polyamide for use.

Recommendation: Anneal polyamide parts, then machine them, and condition them last.

17.8–28.7 %	30.1–30.8 %	24 h
Degree of crystallinity as printed, DLR	after 24 h annealing in a drying oven	Holding time for F3 PA-CF Pro

01 BACKGROUND

An FFF part is not finished after the last layer. Anyone who wants to reach the data sheet values in use has to treat the part specifically after printing.

The reason lies in the process itself. Each bead is deposited at 270 to 300 °C and cools to chamber temperature within seconds. Semi-crystalline plastics such as polyamide have hardly any time to crystallise. At the same time, residual stresses freeze in, because each new bead shrinks on a substrate that has already cooled.

WP002 showed how strongly moisture determines printability. This paper starts after that: it covers what happens to the part after printing. This includes:

- **Annealing:** targeted heat treatment to increase crystallinity and relieve residual stresses
- **Conditioning:** controlled moisture uptake in polyamide to set the toughness for use
- **Mechanical finishing:** removing supports, drilling, threads, threaded inserts
- **Surfaces:** sanding, dyeing, painting, sealing

The recommendations are arranged by Fiberthree material family. They are aimed at everyone working with our filaments, from the first prototype to small series.

FIG. 1: SCHEMATIC

DETAIL A . STRUCTURE AFTER ANNEALING

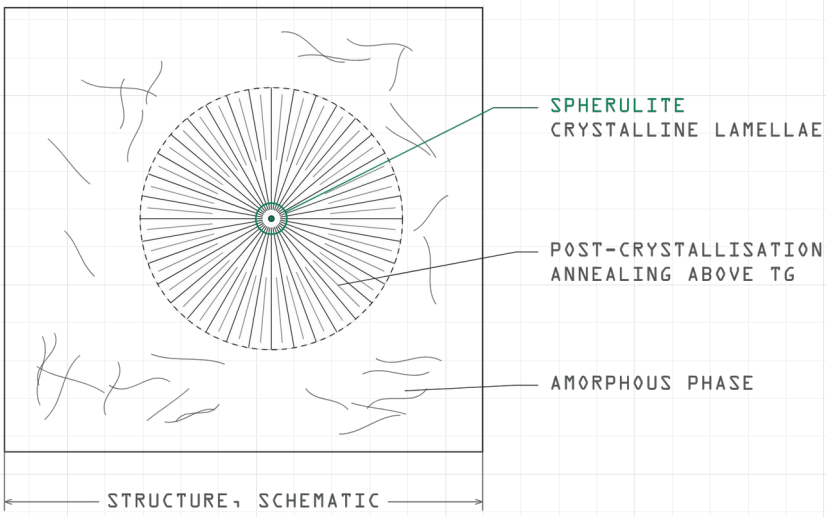


FIG. 1 Structure with a spherulite in the amorphous phase after annealing, schematic, not to scale.

02 WHAT HAPPENS DURING ANNEALING

Annealing means: the part is heated above the glass transition temperature (Tg) but well below the melting temperature (Tm) and held there. Two processes take place that cannot be separated.

Post-crystallisation. Semi-crystalline plastics such as PA6, PA12 and PP consist of ordered (crystalline) and disordered (amorphous) regions. In FFF printing the melt cools so fast that hardly any crystals grow. Above Tg the chains become mobile again and rearrange. Higher crystallinity means higher stiffness, better heat deflection temperature and lower moisture uptake.

Stress relief. Each bead shrinks on cooling on a substrate that has already solidified. The resulting residual stresses are relieved during annealing. This also applies to amorphous plastics such as PC, which do not crystallise.

MEASURED DATA ON F3 PA PURE PRO

In 2026 the University of the Bundeswehr Munich investigated the thermal behaviour of our unfilled F3 PA Pure Pro (Klingenbeck, Lion, Johlitz, Polymers 18(8), 981). The results show why annealing works for polyamide:

PROPERTY	PRINTED PART	AFTER HEAT TREATMENT UP TO 140 °C
Crystallinity (DSC)	7.5–12 %, almost amorphous	approx. 18 %
Glass transition Tg	approx. 75 °C	–
Cold crystallisation	peak at approx. 110 °C	disappeared
Melting peak Tm	approx. 235 °C	–

TAB. 1 Measured data on F3 PA Pure Pro.

The printed specimens were as amorphous as specimens quenched in ice water. During the first heating, thermomechanical analysis showed two shrinkage steps: at about 70 °C (stress relief at the glass transition) and at about 100 °C (cold crystallisation). From the second heating onwards no further shrinkage occurred.

Fibres change this picture. They act as nucleating agents: in the carbon-fibre-reinforced F3 PA-CF Pro, DLR measured 18 to 29 % crystallinity already in the printed state (Chapter 09). Annealing still raises it considerably there, too.

In practice this means: a printed PA6 part will shrink the first time it is heated above about 70 °C, whether in the oven or later in use. Annealing under control moves this shrinkage before the final inspection instead of into the application.

In practice this means: annealing is not fine-tuning but a process step with a measurable effect. It compensates for what printing cannot achieve and makes parts comparable that were made on different printers or at different positions in the build space.

How strong the effect is depends on the material. Semi-crystalline plastics gain mainly from post-crystallisation, amorphous plastics mainly from stress relief. The recommendations in Chapter 04 take both into account.

03 ANNEALING IN PRACTICE

Good annealing does not need an industrial oven, but it does need a stable temperature, patience during cooling and a part that is prepared for it.

EQUIPMENT

- **Convection oven or heating cabinet** with a temperature stability of ± 3 K. The drying oven from WP002 is suitable if it reaches the required temperature.
- **Independent thermometer** in the chamber. The display of many ovens is off by 5 to 10 K.
- **Base** of metal or glass, flat and clean. Thin, long parts can be embedded in dry sand or salt so that they do not warp.

Kitchen ovens are only suitable to a limited extent: the temperature fluctuates strongly, and plastic fumes have no place in food appliances.

PROCEDURE

01	**Prepare the part.** Supports stay on; they keep overhangs in shape. The part lies flat on its largest contact surface.
02	**Heat up slowly.** Heat up together with the part, do not put it into a hot oven. Guide value: 20 to 30 K per hour. For polyamide an intermediate step 20 to 30 K below the target temperature helps.
03	**Hold.** The holding time starts when the part is heated through, not when the oven shows the temperature. Rule of thumb: an additional 1 hour per 10 mm wall thickness.
04	**Let it cool in the oven.** Switch off the oven and keep the door closed. Target: below 30 K per hour until below the glass transition temperature. Fast cooling builds up new stresses.
05	**Check dimensions.** Measure only after complete cooling and compare with the values before annealing.

ALLOWING FOR SHRINKAGE AND WARPING

Annealing changes the dimensions. Semi-crystalline plastics become denser and shrink, usually more in the build plane (x-y) than in the build direction (z). For PLA, about 2 % shrinkage in x-y and up to 1 % elongation in z are known. Fibre-reinforced grades shrink considerably less in the fibre direction.

DLR measurements on F3 PA-CF Pro show how much direction matters. Thermal expansion there depends extremely on the direction:

DIRECTION	EXPANSION 20–60 °C	EXPANSION 100–150 °C
Print direction	19 µm/(m·K)	21 µm/(m·K)
90° to print direction	60 µm/(m·K)	102 µm/(m·K)
Build direction (z)	98 µm/(m·K)	249 µm/(m·K)

TAB. 2 Allowing for shrinkage and warping.

In the annealing range, the material therefore expands more than ten times as much in the build direction as along the fibres. The orientation in printing thus determines where a part moves during annealing.

This leads to three rules:

- **Test specimen first.** Anneal a cube or a reference part of the same wall thickness alongside and measure the shrinkage per axis. Allow for the value as scaling in CAD or the slicer.
- **Produce functional dimensions after annealing.** Fit holes, threads and threaded inserts come only after annealing (Chapter 06).
- **Support the geometry.** At least 3 to 5 perimeters and at least 50 % infill. Hollow and thin-walled parts warp considerably more.

POLYAMIDE IN THE OVEN

Polyamide dries out completely during annealing. Directly after the oven it is therefore more brittle than in use. Chapter 05 describes how to restore the toughness in a controlled way. At temperatures from about 120 °C in air, uncoloured polyamide can turn yellowish. Where appearance matters, anneal under nitrogen or at a lower temperature with a longer holding time.

04 RECOMMENDATIONS BY MATERIAL FAMILY

The polyamides benefit most from annealing, because they come out of the printer almost amorphous. PC is only stress-relieved, and PP generally needs no heat treatment.

MATERIAL FAMILY	FIBERTHREE FILAMENTS	GOAL	TEMPERATURE	HOLDING TIME	IMPORTANT
PA6 filled	F3 PA-CF Pro, F3 PA-GF Pro, F3 PA-GF30 Pro	Crystallinity, stiffness, stress relief	75 °C (in the drying oven)	24 h	Measured by DLR for PA-CF Pro (Section 3.8). Faster: 120 °C, 2–6 h. With glass fibre no long holding times above 150 °C
PA6 unfilled	F3 PA Pure Pro, F3 PA ESD	Crystallinity, dimensional stability	120 °C	4–6 h	Cold crystallisation only from approx. 110 °C (Section 3.1). Check the ESD value after annealing
PA6 transparent	F3 PA Ortho	stress relief only	not without consulting us	–	Crystallisation can cloud the transparency
PA12	F3 PA-CF Lite, F3 PA Pure Lite	Crystallinity, bending stiffness	120–135 °C	3–6 h	Not above 150 °C
PC	F3 PC CF 150	stress relief only (amorphous)	20–30 K below Tg	1–2 h	Anneal directly after printing, cool very slowly
PP	F3 PP GF 25	–	generally not needed	–	PP crystallises quickly during printing
PLA	F3 PLA GF	Heat deflection temperature	80–90 °C	1 h	Strong shrinkage, embed the part in sand
TPU	F3 TPU 80A, F3 TPU 98A	–	not needed	–	–

TAB. 3 Recommendations by material family.

The recommendations are based on DLR measurements on F3 PA-CF Pro as well as on the studies cited below and manufacturer information. The temperature at which a specific part starts to warp depends on geometry, infill and wall thickness. A test specimen before the series is therefore always worthwhile.

WHAT THE STUDIES SHOW

- **PA6-CF:** Annealing increased tensile strength by up to 16.7 % and tensile modulus by up to 35 %. Elongation at break dropped by up to 35 %. The optimum was at 170 °C, close to softening and with a risk of warping. At lower temperatures the tensile properties did not change in this study (Tujmer & Pilipović 2025).
- **PA6-CF and PA6-GF30 compared:** At 180 °C a carbon-fibre-reinforced PA6 gained about 18 % tensile strength after 30 minutes, and nothing more after that. PA6-GF30, on the other hand, lost with every minute: about 32 % after 100 minutes (Boszorádová et al. 2026). This is why we recommend moderate temperatures for glass-fibre-reinforced grades.
- **In the build direction (z):** For short-fibre-reinforced PA6, the modulus in z tripled and tensile strength rose by 50 % (RMIT). Annealing therefore helps exactly where FFF parts are weakest.
- **PA12:** Annealing was done at 135 to 165 °C for 3 to 18 hours. Short-fibre-reinforced PA12 gained about 11 % in strength and stiffness. At 165 °C the values dropped due to material degradation (Ferreira et al. 2020).
- **PC:** Polycarbonate is stress-relieved just below Tg, typically for 1 hour, and cooled at 10 to 30 K per hour. If Tg is exceeded, the part deforms. The glass transition temperature of F3 PC CF 150 is given in the technical data sheet.

05 CONDITIONING POLYAMIDE

Dry polyamide is stiff but brittle. It gains its typical toughness only from absorbed water. Moisture that is harmful in the filament (WP002) is therefore wanted in the finished part, just in a controlled way.

Conditioning means: the part is stored until it is in moisture equilibrium with its surroundings. The reference is the standard climate of 23 °C and 50 % relative humidity. PA6 absorbs up to 3.5 % water. Strength and stiffness drop, elongation at break and impact strength rise.

The data sheet values of an unfilled injection-moulded PA6 show how large the difference is:

PROPERTY	DRY	CONDITIONED (23 °C / 50 % RH)
Tensile modulus	3,100 MPa	1,000 MPa
Yield stress	80 MPa	40 MPa
Charpy notched impact strength 23 °C	5.5 kJ/m²	60 kJ/m²

TAB. 4 Conditioning polyamide.

Fibre-reinforced grades react less strongly, because the fibres absorb no water. PA12 (F3 PA Lite) absorbs considerably less moisture than PA6 (F3 PA Pro) and changes correspondingly less. The Fiberthree data sheets state the effect of moisture uptake for each material.

CONDITIONING IN PRACTICE

- **Passive:** store the part in room climate. This is simple but takes time: at 2 to 3 mm wall thickness, equilibrium can take several months.
- **Accelerated:** storage at elevated temperature and humidity, for example to ISO 1110 or at 80 °C and 60 % RH. This reaches a moisture content similar to the standard climate within days (Bosch / IPF Dresden, Polymers 2023).
- **In a water bath:** fast, but it leads to over-conditioning. The part absorbs more water than in use and must then re-condition in air.

POINTS TO WATCH

- **Dimensions change.** Polyamide swells when it absorbs water. Always check fit dimensions in the state in which the part is used.

- **The order matters:** anneal first, then condition. Annealing dries the part out completely.
- **Define the operating conditions.** A part in an air-conditioned laboratory stays drier than one outdoors. The design should assume the least favourable state: dry for impact, moist for stiffness.

Conditioning is particularly important when a part has to withstand impacts, bending or frequent assembly. Freshly annealed, dry polyamide is stiff but more brittle than in its operating state. Only with moisture from the environment does it reach the toughness for which polyamide is valued.

The same applies to fits as to annealing: check dimensions in the state in which the part is used. This way swelling and shrinkage do not first become apparent during assembly.

06 MECHANICAL FINISHING

Fibre-reinforced filaments machine well, but the fibres call for suitable tools and protection from dust.

REMOVING SUPPORTS

- Remove supports only **after** annealing so that overhangs keep their shape.
- Polyamide is tough. Supports are best removed with side cutters and a deburring tool, not by breaking them off.
- If the part has been conditioned beforehand, the supports come off more easily, because the material is tougher and less brittle.

DRILLING, MILLING, TAPPING

- **Tools:** for carbon and glass fibre use carbide instead of HSS. The fibres are abrasive and quickly blunt HSS cutting edges.
- **Fit holes:** design them 0.2 to 0.3 mm smaller in the print and drill or ream them to size after annealing.
- **Cutting data:** high speed, low feed, no heat build-up. Otherwise the cutting edge smears with polyamide.
- **Threads** cut directly into the plastic only for joints that are rarely released. For frequent assembly, threaded inserts are the better choice.

HEAT-SETTING THREADED INSERTS

Brass threaded inserts give the part a metal thread that withstands many assembly cycles.

01 **Order:** anneal first, then heat-set. Otherwise the hole shrinks around the insert and stresses build up.

02 **Design:** hole diameter as specified by the insert manufacturer, 4 to 6 perimeters around the hole in the slicer.

03 **Temperature:** soldering iron 10 to 20 °C above the print temperature of the material. For F3 PA-CF Pro with a nozzle temperature of 270 to 285 °C, that is about 290 to 300 °C.

04 **Inserting:** insert straight, heat-set only about 90 % of the length and press the rest flush with a cold, flat tool. This keeps the surface flat.

OCCUPATIONAL SAFETY WITH FIBRE DUST

Sanding, drilling and milling fibre-reinforced plastics produces fine dust. Carbon dust is also electrically conductive.

- Work with extraction, preferably sand wet.
- Wear at least FFP2 respiratory protection, FFP3 for longer work.
- Keep electronics and open devices away from the workplace.
- Follow the safety data sheet of the respective filament.

07 SURFACES

For many functional parts, the matt surface of the fibre-reinforced filaments is already the end result. Where appearance, tightness or colour are required, the following methods help.

METHOD	SUITABLE FOR	NOTES
Sanding	all	Sand wet, increase the grit step by step. With carbon and glass, sanding exposes fibres and the surface becomes rougher rather than smoother. Then fill or prime.
Dip dyeing	unfilled PA, e.g. F3 PA Pure Pro	Polyamide takes up acid and textile dyes well in hot water. The part is conditioned at the same time (Section 3.4). Check dimensions afterwards.
Painting	PA, PC, PLA	Degrease, scuff, use an adhesion primer for plastics. 2K paints hold better on polyamide than 1K spray paint.
Painting PP	F3 PP GF 25	PP has a very low surface energy. Without a special adhesion promoter or pre-treatment (flame, plasma), hardly any paint holds.
Sealing	all	Low-viscosity epoxy closes pores and makes parts tight against liquids and gases. It also increases surface hardness.

TAB. 5 Surfaces.

Sequence for polyamide: anneal, machine, then dye or paint. Paint on a part that has not yet been annealed can crack when it is later heated, because the part underneath shrinks.

08 POST-PROCESSING GUIDELINES

For polyamide parts we recommend this sequence:

01	**Print** with dried filament (WP002)
02	**Anneal** with supports according to the table in Chapter 04, for F3 PA-CF Pro in the drying oven at 75 °C for 24 hours
03	**Remove supports**
04	**Machine:** fit holes, threads, threaded inserts
05	**Surface:** sand, dye, paint or seal
06	**Condition** to the moisture content in use
07	**Final inspection** of dimensions in the operating state

CASE	RECOMMENDATION
Prototype, form check	No annealing needed
Functional part, room temperature	Annealing recommended: higher stiffness, more uniform properties throughout the part
Part gets warmer than 70 °C in use	Annealing required, otherwise it shrinks in use
Tight fits	Anneal, then machine functional dimensions to size
Impact load, snap fits	Condition after annealing
Same properties from different printers	Annealing evens out differences (Section 3.8)

TAB. 6 Post-processing guidelines.

09 EXPERIMENTAL DATA

The German Aerospace Center (DLR) in Braunschweig examined F3 PA-CF Pro on three printers in the EmpowerAX project: Prusa, Raise3D and Intamsys. Specimens were taken from the top, middle and bottom of each part and measured by DSC (0 to 280 °C, 10 K/min, under nitrogen). A further specimen was post-crystallised for 24 hours at 75 °C.

FIG. 2: EXPERIMENTAL DATA

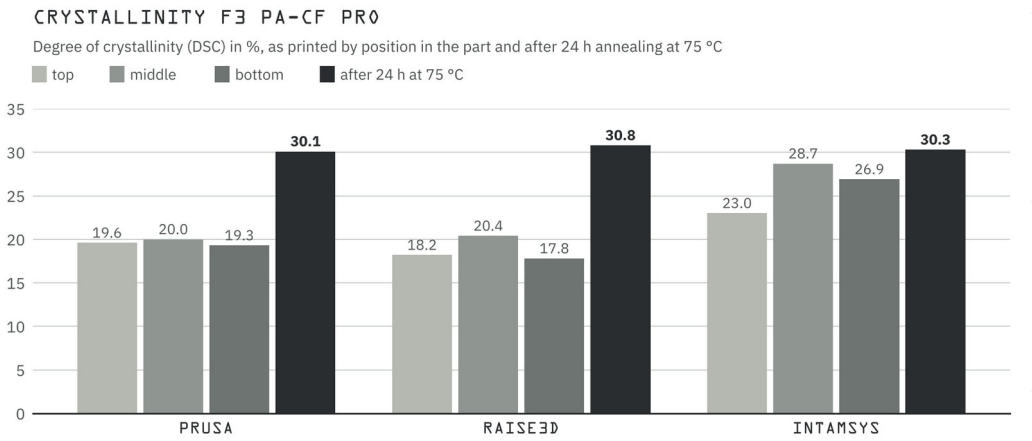


FIG. 2 DLR Braunschweig, project EmpowerAX: material characterisation of Fiberthree polyamide filaments (2023), DSC measurement

The printed state therefore depends on the printer and on the position in the part. On the Intamsys the material crystallised more already during printing. After annealing these differences disappear: all three printers end up at about 30 %.

That is the most important finding for practice. Annealing gives reproducible parts, regardless of the printer on which they were made. And the temperature used in WP002 to dry the filament is enough.

In the same project DLR showed how much the print direction matters. The tensile strength of F3 PA-CF Pro is 115.7 MPa in the print direction. In the build direction (z) the specimens reached only 21 to 29 MPa depending on the printer. That is exactly where annealing comes in (Chapter 04).

Outlook: The mechanical properties after annealing were not measured in this project. Tensile tests on annealed specimens in x-y and z would quantify the effect for F3 PA-CF Pro directly; our own tests on this are still pending.

10 CONCLUSION

Polyamide FFF parts leave the printer with low crystallinity and frozen-in stresses. Annealing compensates for this and makes parts reproducible regardless of the printer, for F3 PA-CF Pro even in a drying oven at 75 °C. Machining and surface finishing follow, and finally conditioning to the moisture content in use.

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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. The ecosystem includes carbon build plates and the F3 Safe Light and F3 Safe Long Run dry boxes.

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 (this paper)**	**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	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. 7 Overview of the Fiberthree white papers.

FIBERTHREE

START WITH THE RIGHT MATERIAL

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