WERKSTOFFWERK · POLYMER SCIENCE

Polymer Science for Additive Manufacturing

Polymer structure, thermal behaviour, hygroscopy and drying, mechanics, ageing, rheology, additives and the printing polymers at a glance

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Note

This materials foundation summarizes the state of polymer technology insofar as relevant to additive manufacturing (June 2026).

Specific values are typical orientation values and vary with manufacturer, batch and test condition; they do not replace a data sheet. Schichtwerk is a contract manufacturer.

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Part I
Structure and Classes of Polymers

1. What a Plastic Is

Plastics (polymers) are materials made of macromolecules – long chains formed by linking many identical building blocks (monomers). The three formation routes are polymerization (chain growth, e.g. PE, PP, PS, acrylates), polycondensation (with elimination of small molecules, e.g. PA, PET, PC) and polyaddition (e.g. PU). Chain length (molar mass) and branching determine essential properties. [1]

2. The Three Main Classes

Class	Cross-linking	Behaviour on heating	Examples (AM)
Thermoplastics	none (linear/branched chains)	soften reversibly, meltable	PLA, ABS, PETG, PA (FDM)
Thermosets	densely cross-linked	cure irreversibly, not meltable	photopolymers (SLA, after curing)
Elastomers	loosely cross-linked	rubber-elastic	TPU/TPE (thermoplastic elastomers)

For additive manufacturing, thermoplastics (FDM) and curing photopolymers (SLA/DLP) are especially relevant. Thermoplastic elastomers (TPU) combine meltability with rubber elasticity.

3. Amorphous or Semi-crystalline

Thermoplastics are either amorphous (disordered chains, e.g. ABS, PC, PETG, PS) or semi-crystalline (ordered regions alongside amorphous ones, e.g. PLA partly, PA, PP, PE). Amorphous plastics soften over a broad range around the glass transition temperature (Tg) and warp less; semi-crystalline ones have a distinct melting point (Tm), higher chemical resistance but greater shrinkage/warping. [2]

Part II

Thermal Behaviour

4. The Important Temperatures

Quantity	Meaning
Glass transition Tg	hard → tough/soft transition; above it the part loses stiffness
Melting temperature Tm	semi-crystalline only; solid → molten transition
Heat deflection (HDT)	temperature at which the part deforms under load (ISO 75)
Vicat softening	penetration temperature of a needle under load (ISO 306)
Print/bed/chamber temperature	process-side temperatures in FDM

Practical relevance

A part's service temperature is, as a rule of thumb, limited by Tg (amorphous) or HDT. PLA with Tg ~55–60 °C is therefore unsuitable for hot environments.

High Tm/HDT (PA, PC, PEEK) mean higher print and often chamber temperatures and thus more demanding processing.

5. Thermal Expansion, Shrinkage and Warping

On cooling, thermoplastics shrink; semi-crystalline more than amorphous. Uneven cooling creates residual stresses and warping, especially with large, flat ABS/PA parts. Countermeasures are a heated bed, an enclosed chamber (chamber temperature) and suitable design (fillets, brim/raft). [3]

Part III

Hygroscopy and Drying

6. Why Plastics Absorb Water

Many polymers are hygroscopic: they absorb moisture from the air because polar groups (e.g. amide groups in PA, ester groups in PET/PLA) bind water molecules. The extent ranges from a few tenths of a percent to several percent of mass. Absorbed water is relevant to processing and properties. [4]

7. Effect of Moisture During Printing

- Steam bubbles at the nozzle: water flashes to vapour → crackling, popping, pores, rough surface, stringing.
- Hydrolytic chain scission: at high nozzle temperatures water cleaves the chains (especially PA, PET/PETG, PLA, PC) → molar mass drops → strength and toughness fall measurably.
- Dimensional/diameter fluctuations of the filament from swelling; unstable material flow.
- Poorer layer adhesion and brittleness in the finished part.

8. Hygroscopy Profile of Printing Materials

Material	Moisture uptake	Drying (guideline)
PVA (support)	very high	45 °C, long; very sensitive
PA / nylon	high (several %)	70–80 °C, 8–12 h
PC (polycarbonate)	high	70–90 °C, 6–12 h
TPU / TPE	medium–high	50–65 °C, 4–8 h
PETG / PET	medium	60–65 °C, 4–6 h
ASA	low–medium	60–70 °C, 4 h
ABS	low	60–70 °C, 4 h
PLA	low, but hydrolysis-sensitive	40–45 °C, 4–6 h

Drying and storage – practice

Dry below the glass transition temperature, otherwise spools stick together. Use a filament dryer or convection oven with accurate temperature.

Dry storage: sealed boxes with desiccant (silica gel), humidity indicator; do not leave opened spools exposed.

When in doubt, always dry before demanding prints (PA, PC, PETG) – the strength loss from moisture is real and often underestimated.

Part IV
Mechanics, Chemistry and Ageing

9. Mechanical Properties

- Young's modulus (stiffness), tensile strength, elongation at break – brittle (PLA) vs. tough (PETG, PA, PC).
- Impact strength – ABS/PC/PA high, PLA low; relevant for impact-loaded parts.
- Creep – permanent deformation under sustained load, especially near Tg; account for it under sustained load.
- Anisotropy in FDM – Z-strength 40–70 % of XY (see limits paper).

10. Chemical Resistance

Semi-crystalline plastics (PA, PP, PE) are chemically more resistant than amorphous ones. ABS and PLA are attacked by many solvents (acetone for ABS); PETG is relatively resistant. Environmental stress cracking (ESC) occurs when a medium acts on a mechanically stressed amorphous part (e.g. PC under load with an aggressive cleaner). [5]

11. Ageing and Degradation

Mechanism	Trigger	Particularly affected
Photo-oxidation (UV)	sunlight	PLA, ABS (embrittlement, yellowing); ASA UV-stable
Hydrolysis	moisture + heat	PLA, PET/PETG, PA, PC
Thermo-oxidation	heat + oxygen	many, without stabilizers
Biodegradation	compost/moisture	PLA (intentionally biodegradable)

Part V
Rheology and Additives

12. Melt Behaviour (Rheology)

In FDM the polymer melt is forced through a nozzle. Thermoplastic melts are shear-thinning: viscosity decreases with increasing shear rate. The melt flow index (MFI/MVR) describes flowability. Too low a temperature → under-extrusion and poor adhesion; too high → stringing, thermal degradation. [6]

13. Additives and Fillers

Additive	Function
Plasticizers	increase flexibility (e.g. in TPU formulations)
Stabilizers (UV/thermal)	delay ageing (e.g. ASA UV-stable)
Colour pigments	colour; can affect crystallization/strength
Flame retardants	reduce flammability
Reinforcing fibres (CF/GF)	increase stiffness/strength; abrasive → hardened nozzle
Fillers (wood, metal)	look/feel; alter processing

Part VI
The Printing Polymers at a Glance

14. FDM Filaments – Brief Profiles

Material	Character	Strength / weakness
PLA	amorph/semi-cryst., easy to print	easy, stiff / brittle, heat-sensitive
PETG	amorphous, tough	robust, chemically resistant / stringing, moisture-sensitive
ABS	amorphous, technical	impact-resistant, heat-resistant / styrene, warping
ASA	amorphous, UV-stable	outdoor-capable / like ABS in processing
PA / nylon	semi-crystalline, tough	tough, abrasion-resistant / strongly hygroscopic
PC	amorphous, high-strength	very strong/heat-resistant / high temp, hygroscopic
TPU/TPE	elastomer	flexible, rubber-like / slow to print
CF/GF-filled	reinforced	stiff, dimensionally stable / abrasive, more brittle
PVA/HIPS	support material	soluble / PVA very hygroscopic

15. Photopolymers (SLA/DLP)

Photopolymers cure under UV light by radical cross-linking (thermoset). They yield the finest detail and smooth surfaces but are skin-sensitizing in the raw state (see occupational-safety handbook) and, after curing, often more brittle and more UV/temperature-sensitive than engineering thermoplastics. The degree of cure determines strength and safety. [7]

Part VII
Property Overview and Processing

16. Typical Values (Orientation)

Material	Tg/HDT (°C)	Nozzle (°C)	Bed (°C)	Hygrosc.
PLA	~55–60	190–220	20–60	low
PETG	~70–80	230–250	70–85	medium
ABS	~100	230–260	90–110	low
ASA	~100	240–260	90–110	low–med
PA	~70–180*	250–290	80–110	high
PC	~140	260–300	100–120	high
TPU	~60–80	210–240	30–60	med–high

** PA values strongly type-dependent. All values are orientation; the manufacturer's data sheet of the specific batch is authoritative.*

17. Material Choice – Quick Guide

- Prototype/decor, simple: PLA.
- Robust, everyday, chemicals: PETG.
- Outdoor/UV: ASA.
- Impact/temperature: ABS, PC.
- Tough/abrasion-resistant, functional parts: PA (dry it!).
- Flexible: TPU. Finest detail/aesthetics: resin (SLA).

Declarations

Conflict of interest: The author operates Schichtwerk, a service company in additive manufacturing. This work reflects the published state, without external funding.

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