Knowledge compendium – types of filaments

ABS (acrylonitrile butadiene styrene) – a filament belonging to the group of technical materials used in 3D printers working in additive technology (FDM). Due to its strength properties, it is very often used in printing functional prototypes. The disadvantage of the material is primarily the need to ensure stable temperature conditions during printing, and to ensure a sufficiently strong adhesive surface of the work table, because **ABS** is distinguished by a large shrinkage. **ABS**, similarly to **PLA** and **PETG**, is available in a very wide range of colors, but color dyes have an impact on changes in strength properties and the quality of finished printed models. **ABS** is characterized by moisture absorption, so to maintain its properties, it should be kept in dry conditions. Moistened **ABS** is characterized by the fact that during the 3D printing process you can hear characteristic "crackles" coming out of the nozzle tip, despite the correctly set printing temperature. Moistened **ABS** has much worse properties, which is reflected directly on the printed model.

- High shrinkage,
- Heated bed recommended (90°C – 110°C),
- Heated chamber recommended (35°C – 50°C),
- The vapors of melted ABS are toxic,
- An unpleasant smell during printing,
- Soluble in acetone,
- Low abrasion resistance,
- Low material density,
- Cheap material,
- High heat resistance,
- Moisture absorption,
- Slight loss of strength properties under the temperature's influence,
- High impact strength,
- Typical printing temperatures (240°C - 260°C).

In addition to standard **ABS**, manufacturers offer **modified ABS**, which is characterized by less shrinkage, no requirement for printing in a closed heated chamber, reduction of toxic fumes generated in the 3D printing process.

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ASA (Acrylonitrile Styrene Acrylic) - a filament belonging to the group of technical materials used in 3D printers working in incremental technology (FDM). The basic properties are not much different from **ABS**. A feature that differentiates **ASA** from **ABS** is UV and weather conditions resistance. Prints from **ASA** material can be successfully used wherever there is contact with external bad weather conditions e.g. (rain, winds, sub-zero temperatures, exposure to sunlight). The advantage of **ASA** material is high impact strength at sub-zero temperatures, unlike **ABS** material**. ASA** is distinguished by high shrinkage. **ASA**, similarly to PLA and PETG, is available in a very wide range of colors, but color dyes have an impact on changes in strength properties and the quality of finished printed models. **ASA** is characterized by moisture absorption, so to maintain its properties, it should be kept in dry conditions. Moistened **ASA** is characterized by the fact that during the 3D printing process you can hear characteristic "crackling" coming out of the nozzle tip, despite the correctly set printing temperature.

- High shrinkage,
- Heated bed recommended (90°C – 110°C),
- Heated chamber recommended (35°C – 50°C),
- The vapors of melted ABS are toxic,
- An unpleasant smell during printing,
- Soluble in acetone,
- Low abrasion resistance,
- Low material density,
- Cheap material,
- High heat resistance,
- Moisture absorption,
- UV resistance,
- Weather conditions resistance,
- slight loss of strength properties due to sub-zero temperatures,
- High impact strength,
- typical printing temperatures (240°C - 260°C).

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BVOH (high performance vinyl alcohol copolymer) – A popular support material used in 3D printers working in additive technology (FDM). Like **PVA**, **BVOH** dissolves in water, but the whole process is more efficient and faster. **BVOH** is also very easy to print compared to traditional **PVA**. The disadvantage is the quite high price of the material.

- Soluble in water (warm water speeds up soluble process)
- Heated bed not require
- Typical printing temperatures (190°C – 210°C),
- Possibility to print with materials requiring higher printing temperatures (ABS,ASA,PA)
- High moisture absorption,
- Easy to print.

HIPS (High impact polystyrene) – technical material with strength properties similar to **ABS**, characterized by high impact strength. Due to the printing environment requirements similar to **ABS**, it is most often used as a soluble support material for prints from **ABS** material. **HIPS**, like **ABS**, is characterized by moisture absorption. Most often it appears in a milky color and it is a natural color of this material. Depending on the filament producers, **HIPS** may be colored, however any additions of color dye may change the properties of the material.

- Biodegradable,
- Common support material for ABS prints
- Material properties similar to ABS,
- High shrinkage,
- Vapors during printing process are toxic,
- Heated Bed recommended (90°C – 110°C),
- Heated chamber recommended (35°C – 50°C),
- Soluble in Limonene
- Very low material density (the lightest material available in FDM technology),
- Typical printing temperatures (235°C - 245°C).

Special materials – Many of filaments producers has a lot of interesting varieties of standard materials such as: PLA, ABS, PETG, PA. Compared with the usual, "pure" varieties of filaments, those special materials are enhanced with addons that increase mechanical strength properties, or allow you to create eye-catching models visually. The most commonly used addons to improve material strength properties are:

- **Carbon fiber -** filaments enhanced by carbon fibers, usually have in the name "**CF, + CF, CF15, + CF15%**" where the number next to the **CF** symbol indicates the percentage presence of carbon fibers in the filament. All types of filaments with the addition of carbon fiber are available in black color. For printing from **CF** filaments, it is recommended to use special hardened steel nozzles, because they have a much higher abrasion resistance than traditional brass nozzles.
- **Glass fiber -** filaments enhanced by glass fibers usually have in the name "**GF, + GF, GF15, + GF15%**" where the number next to the **GF** symbol indicates the percentage presence of the glass fibers in the filament. For printing from glass fiber filaments, it is recommended to use special hardened steel nozzles because they are much more resistant to abrasion than traditional brass nozzles.

There are filaments for 3D printed models that have contact with electronic components sensitive to electrostatic discharge. Such filaments have anti-static properties. Usually these are appropriately modified **PLA, ABS, PETG** materials.

- **ESD** – filaments marked with this symbol have anti - static properties. Electrostatic filaments are made on the basis of **PLA, ABS, PETG**.

3D printing is used not only to prototype construction elements, but also to produce artistic models, elements of dioramas. Filaments producers have a very wide range of custom materials that allow you to improve the look of models.

- **Copper** – a popular type of filament, based on PLA, enhanced by copper. Printed model can be polished in postprocessing the polished 3D printed model imitates a model made of copper. For printing from metal-enhanced filaments, it is recommended to use special hardened steel nozzles because they are much more wear resistant than traditional brass nozzles.
- **Iron / magnetic / aluminum** – type of filaments, based on PLA with addition of iron, magnesium or aluminum (depending on the type). Printed models are clearly heavier, and imitate models made from steel. For printing from metal-enhanced filaments, it is recommended to use special hardened steel nozzles because they are much more wear resistant than traditional brass nozzles.
- **Wood** – type of filament, based on PLA, with addition wood chips. 3D Printed models imitate models made from wood. Models printed using wooden filaments also keeps the characteristic wooden smell. Depending on filament producers, there are many different color tones of wooden filaments, as well as filaments whose color changes depending on the current printing temperature. For 3D printing from wooden filaments, it is recommended to use special hardened steel nozzles because they are much more wear resistance than traditional brass nozzles. Due to the presence of wood particles in the filament, there is a risk of clogging the small diameter nozzles (0.4 mm and smaller).

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- **Glow** – type of filament, based on PLA enhanced with additions that make 3D printed models glow in the dark.
- **Stone / mineral** – type of filament, based on PLA, enhanced with additions that make printed models imitate stone. Due to the presence of chalk particles and other additions in the filament, there is a risk of clogging the small diameter nozzles (0.4 mm and smaller).
- **Glitter** – type of filament, based on PLA enhanced by the addition of glitter particles. The great advantage of glitter filaments is the fact that they perfectly hide imperfections of the model wall surfaces. Due to the presence of glitter particles in the filament, there is a risk of clogging the small diameter nozzles (0.4 mm and smaller).

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PA (Polyamide / Nylon) – technical material with very good mechanical strength properties. One of the most durable materials used in 3D printers, working in additive technology (FDM). There are several types of nylon used in 3D printing, called **PA6, PA6.6, PA12**. Each type has different properties. The disadvantage of the material is, as in the case of ABS, ensuring very stable temperature conditions during printing due to high shrinkage. Another disadvantage is the high moisture absorption. Moistened nylon is practically unusable for printing, due to poor layers adhesion and poor quality of external walls of prints. Nylon designed for 3D printing in FDM technology is available in natural color (similar to milk or cream).

PA6 / PA 6.6

- Lower shrinkage compared to PA12,
- Higher moisture absorption compared to PA12,
- Higher shrinkage than ABS,
- The vapors generated during printing process are toxic,
- High heat resistance(up to 100°C),
- Very good mechanical strength properties
- Heated bed recommended (60°C – 90°C w zależności od producenta),
- Heated chamber recommended (35°C – 50°C),
- High abrasion resistance,
- Typical printing temperatures (250°C – 300°C),
- High chemical resistance.

PA12

- Lower moisture absorption compared to PA6,
- Higher shrinkage compared to PA6,
- Lower impact strength compared to PA6,
- Very good mechanical strength properties,
- Higher shrinkage than ABS,
- High chemical resistance,
- The vapors generated during printing process are toxic,
- Low UV resistance,
- Typical printing temperatures (250°C – 280°C),
- Heated bed recommended (60°C – 90°C),
- Heated chamber recommended (35°C – 50°C).

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PEEK (polyetheretherketone) – Technical material with very high mechanical and chemical strength properties. It is the most mechanically durable material available for printing in additive technology (FDM). It is characterized by very high temperature resistance (depending on the declarations of various producers, the temperature resistance is up to 350 °C). **PEEK** is available as a pure material, as well as in variants enhanced with carbon fiber or glass fiber. The filament is usually available in a color similar to beige or black. For **PEEK + CF** filament it is always black. This material is not recommended for novice users of 3D printers. Printing with **PEEK** material requires experience with appropriate selection of printing parameters and device preparation. This material requires ensuring stable temperature conditions. **PEEK** is characterized by moisture absorption, so to keep its properties, it should be kept in dry conditions. Moistened **PEEK** is unusable and has much worse properties, which is reflected directly on the printed model.

- Very high mechanical strength properties,
- Very high impact strength,
- Very high stiffness,
- Very high heat resistance (up to 350°C)
- Very high chemical resistance,
- The vapors generated during printing process are toxic,
- Heated bed recommended (120°C – 160°C),
- Heated chamber recommended (60°C-100°C),
- Typical printing temperatures (350°C- 450°C),
- Very high material cost,
- Very high material shrinkage,
- Very high moisture absorption,

PC (polycarbonate) – Technical material with very good mechanical strength properties. It is characterized by high impact strength and stiffness. One of the most durable materials used in 3D printers working in additive technology (FDM). Polycarbonate is available in a colorless form, and is characterized by high transparency. Depending on the filament producer, it is possible to buy this material in a basic technical color's version, however, color dye may affect on the materials properties. 3D printing with polycarbonate isn't easy. The main disadvantage of this material is very high moisture absorption and shrinkage. Moistened polycarbonate is completely unusable due to very poor layer adhesion. High shrinkage forces very stable temperature conditions.

- High mechanical strength properties,
- High impact strength
- High stiffness,
- High hardness,
- The vapors generated during printing process are toxic,
- Heated bed recommended (90°C – 140°C),
- Heated chamber recommended (50°C – 60°C),
- Typical printing temperatures (250°C – 320°C),
- High shrinkage,
- Self-extinguishing material,
- High moisture absorption
- High heat resistance (up to 100°C).

PC/ABS (polycarbonate / acrylonitrile butadiene styrene) – Technical material, being a mix of two materials: PC and ABS, usually in proportions **(80% ABS, 20% PC**). By combining these two materials, we get a filament combining the features of ABS and PC, which is a very good alternative when it is necessary to create durable functional prototype parts that would be problematic to print from a clean PC**. PC/ABS** have less shrinkage than classic ABS or PC. This material is characterized by moisture absorption, so to keep its properties, it should be kept in dry conditions. Moisture **PC/ABS** is characterized by the fact that during the 3D printing process you can hear characteristic "crackles" coming out of the nozzle tip, despite the correctly set printing temperature. Moist **PC / ABS** has much worse properties, which is visible directly on the printed model.

- High impact strength,
- High hardness,
- high mechanical strength properties,
- Less shrinkage than ABS or PC,
- less moisture absorption than PC,
- Heated bed recommended (90°C – 120 °C),
- Heated chamber recommended (30°C – 60°C),
- Typical printing temperatures (250°C – 280 °C),
- The vapors generated during printing process are toxic,
- Unpleasant smell during printing process
- slight loss of mechanical strength properties under the influence of high temperature,

PEI (polyetherimide / ULTEM) – Technical material with very high mechanical strength and chemical properties, similar to PEEK. PEI material used in 3D printers working in additive technology (FDM) is often available under the other trade name - **ULTEM**. Comparing PEEK and **PEI** mechanical properties, **PEI** is a weaker material, however, it is characterized by greater simplicity of printing than classic PEEK. A very important advantage of **PEI** is high flame resistance. This material is non-flammable. Like PEEK, **PEI** has high chemical resistance. This material is often used in the aviation industry. PEI is characterized by moisture absorption, so to keep its properties, it should be kept in dry conditions. Moistened PEI is characterized by the fact, that during the 3D printing process you can hear characteristic "crackles" coming out of the nozzle tip, despite the correctly set printing temperature. moist **PEI** has much worse properties, which is visible directly on the printed model

- High mechanical strength properties (similar to PEEK),
- Very High impact strength,
- High stiffness,
- Very high heat resistance (up to 200°C)
- High chemical resistance,
- The vapors generated during printing process are toxic,
- Heated bed recommended (120°C – 160°C),
- Heated chamber recommended (50°C-80°C),
- Typical printing temperatures (350°C- 380°C),
- High shrinkage,
- High moisture absorption,
- Non-flammable material
- High fire resistance
- High material cost (lower than PEEK)

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PETG (Polyethylene terephthalate + glycol) – just like **PLA**, **PETG** is another popular material used in 3D printers working in additive technology (FDM). It is characterized by slightly better mechanical strength properties (especially hardness) compared to **PLA**, and better heat resistance as well as chemical resistance. **PETG** is available in a very wide range of colors. This material should be stored in dry conditions. The influence of moisture has a negative effect on the material properties. A characteristic feature of moist **PETG** is stringing from nozzle at idle head passes, despite the properly configured 3D printing profile.

- Good mechanical strength properties (higher than PLA),
- High hardness,
- slightly shrinkage,
- moisture absorption,
- Heated bed recommended (~60°C),
- good chemical resistance (oils and lubricants like WD-40),
- low UV resistance,
- good abrasion resistance,
- good heat resistance (higher than PLA),
- Typical printing temperatures (230°C - 250°C).

PLA (Polylactide) – one of the basic materials used in 3D printers working in additive technology (FDM). **PLA** is characterized by high simplicity of printing and good mechanical strength properties for most prototype elements, especially decorative ones. **PLA** is available in a very wide range of colors and types. PLA is also not recommended for printing elements that work under load for a long time.

- Biodegradable material,
- Doesn't require heated bed,
- No shrinkage,
- Very low UV resistance,
- Very easy deforms under influence of high temperatures,
- Good mechanical strength properties,
- Typical printing temperatures – (190°C – 230°C).

In addition to the standard **PLA** producers offer many modified versions of **PLA**, which are characterized by higher mechanical strength properties than standard **PLA** mechanical properties and still simplicity of printing.

PMMA (Polymethyl methacrylate / Plexi) – Highly transparent technical material, used in 3D printers working in additive technology (FDM). **PMMA** is characterized by resistance to weather conditions and good UV transmission. It is not a simple material for 3D printing in FDM technology, due to shrinkage and stable temperature conditions within printer's chamber, as well as precise selection of printing parameters. Too low temperature causes poor layer adhesion, too high temperature causes overheating of the material, which leads to decrease quality of model's walls. **PMMA** as a filament is available in the basic range of RGB colors.

- High transparency,
- UV transmission,
- Good weather conditions resistance,
- The vapors generated during printing process are toxic,
- High shrinkage,
- Heated bed recommended (90°C – 110°C),
- Heated chamber recommended (30°C – 40°C),
- Typical printing temperatures (230°C – 250°C).

POM (Polyoxymethylene) – Technical material with high mechanical strength properties, characterized by high stiffness and high chemical resistance (similar to PP). It does not absorb water and is UV resistant. It is not a simple material for 3D printing in FDM technology due to high shrinkage and the need to ensure stable temperature conditions inside the printer's working chamber. **POM** filament is available in black and white color.

- Very high chemical resistance
- High shrinkage,
- High stiffness,
- High impact strength,
- Low friction coefficient,
- High fatigue strength,
- High mechanical strength properties,
- Heated bed recommended (70°C – 120°C),
- Heated chamber recommended (40°C – 60°C),
- Typical printing temperatures (250°C – 280°C),
- The vapors generated during printing process are very toxic,
- Flammable material,
- Non-Extinguishing material.

PP (polypropylene) – Technical material characterized by very high chemical resistance, especially at typical room temperature, and high flexibility. **PP** is almost completely immune to acids, and organic solvents. Polypropylene is a flammable, colorless, odorless and water-proof material. It's not a simple material for 3D printing in FDM technology due to high shrinkage and the ensure stable temperature conditions inside the printer's working chamber. **PP** as a filament is available only in a colorless variety.

- Very high chemical resistance,
- High shrinkage,
- Low material density,
- Elastic material,
- High electric resistance,
- Low friction coefficient
- High fatigue strength,
- Heated bed recommended (70°C – 100°C),
- Heated chamber recommended (40°C – 50°C),
- Typical printing temperatures (240°C – 270°C),
- Very good layer adhesion,
- The vapors generated during printing process are very toxic.

PVA (Polyvinyl alcohol) – A popular support material used in 3D printers working in additive technology (FDM). PVA dissolves in water, which makes it possible to print models with complicated geometry, or such where removal of printed supports from the base material would be impossible due easy access for tools. The disadvantage of **PVA** is the high moisture absorption. Moistened **PVA** is practically unusable, by very frequent clogging in the nozzle and characteristic sounds of "crackling" coming from the nozzle during printing process.

- Soluble in water (warm water speeds up soluble process),
- Doesn't require heated bed,
- Typical printing temperatures – (190^{o}C – 210^{o}C),
- Deforms under the influence of high temperature,
- Very high moisture absorption

TPU (thermoplastic polyurethane) – a rubber-like material used in 3D printers working in additive technology (FDM) to produce prototype elements that must have rubber-like properties. Depending on the producers, TPU is available on various Shore hardness scales and wide range of colors.

- Very good layer adhesion,
- Rubber like properties,
- Good chemical resistance,
- Good mechanical properties,
- Heated bed recommended (w zależności od producenta 40°C – 80°C),
- Low shrinkage (depending on filament producer),
- Low printing speed recommended (20-40 mm/s),
- Typical printing temperatures (200°C – 240°C).

The **TPU** name is accepted for all thermoplastic materials in the form of filaments for 3D printers, working in additive technology (FDM). Producers not always use **TPU** name, and call their materials differently, e.g. (**Flex, Fiberflex, NinjaFlex, Flex MH**).