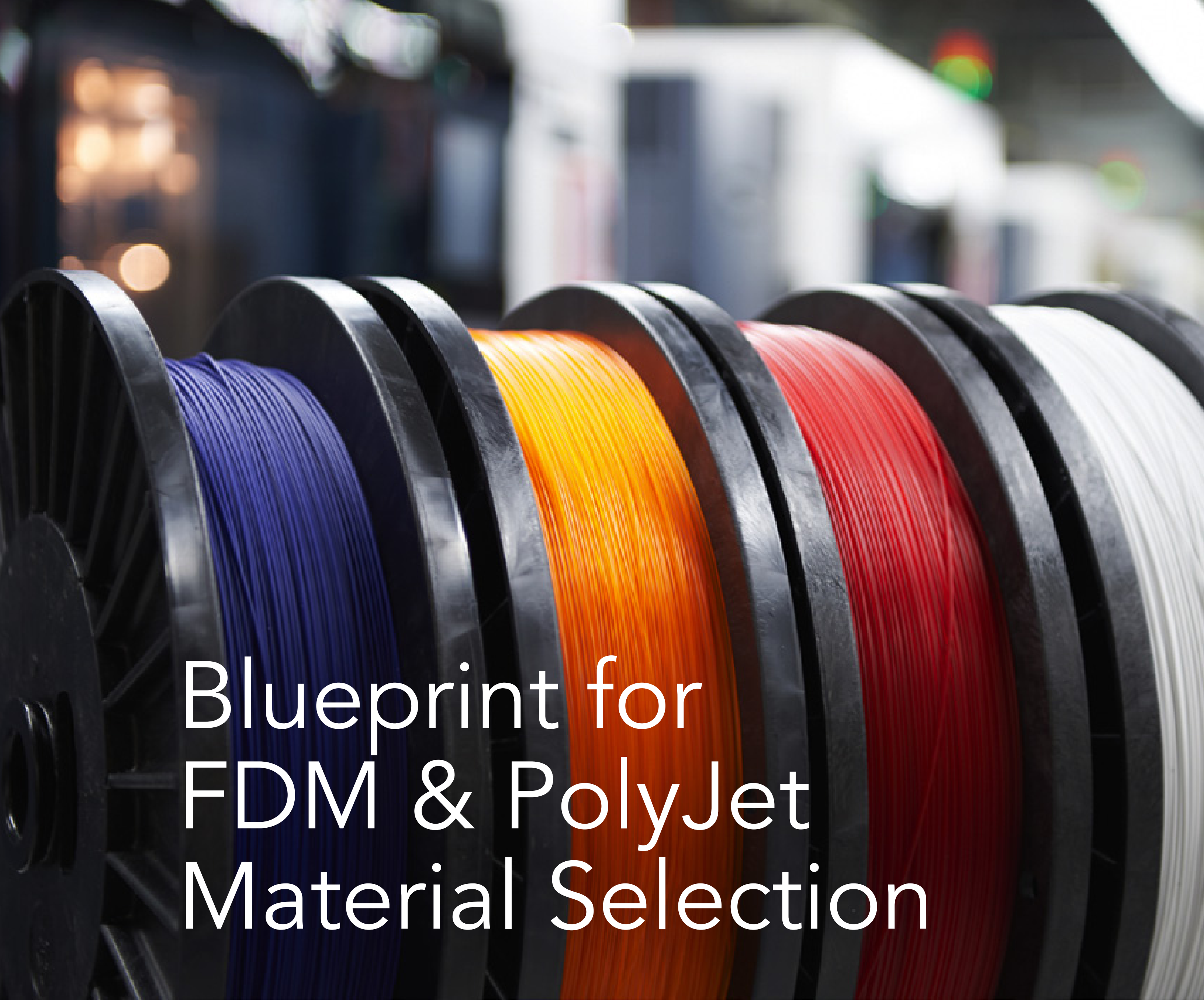


# Blueprint for FDM & PolyJet Material Selection

Most engineers and designers have an expert grasp of material choices for injection molding projects. When it comes to 3D printing, however, material selection can be a very different story. To help you select the best material for the job, challenge yourself to think outside the mold.

RedEye

GIVING YOU MORE THAN 3D PARTS

**Leading 3D printing technologies like Fused Deposition Modeling™ (FDM®) and PolyJet™ are inherently different processes for building parts than injection molding and therefore present a host of unique considerations to help you select the right material for the job. This paper outlines the factors you should consider before selecting the best material for your next FDM or PolyJet project.**

## REDEYE 3D PRINTING TECHNOLOGIES

Additive manufacturing technologies allow you to create high-quality, complex prototypes and functional parts made from a large selection of real, durable thermoplastic materials, including ABS, polycarbonate and ULTEM 9085.

FDM, invented by Stratasys, is the 3D printing process of building an object from a 3D CAD model by depositing successive layers of thin, molten material on top of each other. This additive process is the inverse of traditional manufacturing methods that typically remove or subtract material. The process helps manufacturers improve the speed and efficiency of producing small quantities of complex parts.

PolyJet technology creates concept models and precision prototypes that set the standard for finished-product realism. The printers jet layers of liquid photopolymer onto a build tray and cure them with UV light. Its very thin print layers allow you to achieve complex shapes, fine feature details and smooth finished surfaces. PolyJet technology is compatible with the widest range of material properties on the market and has the ability to print multi-material, multi-color parts.

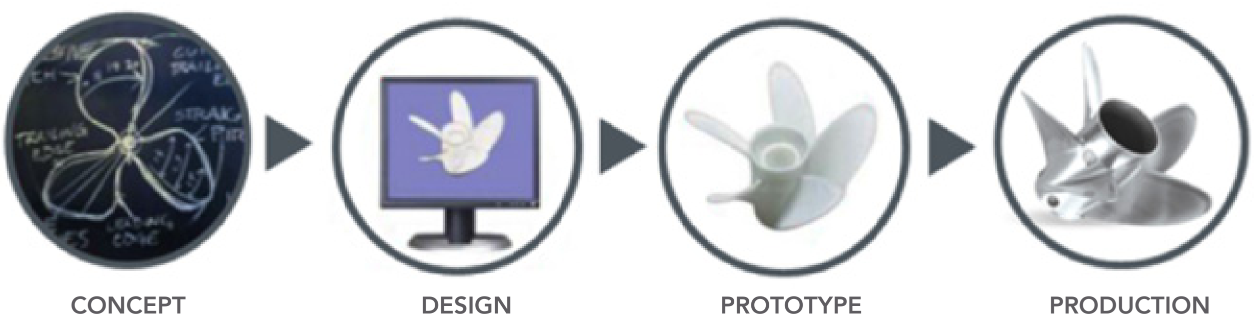
Whether you're using FDM or PolyJet, you must embrace new ways of thinking about design in order to fully leverage the benefits offered by 3D printing. Design decisions can be made to maximize part strength, optimize aesthetics, or combine multiple part components into one build. Two parts that start out with the exact same design can end up with different material properties, based on the orientation of the build or slice thickness. We'll go into more detail on both of these topics later in the paper. For now, knowing that your approach to design will impact material properties gives you additional appreciation for and motivation to understand the material selection considerations presented in this guide.

# FUNCTIONAL AND APPLICATION CONSIDERATIONS

The first thing you need to consider in selecting the right material for the job is: What is the part's intended use? It might seem like a straightforward question, but there are a variety of ways to answer it. It's imperative to consider all aspects of a part's purpose and the environment in which it will function in order to select the material best suited for your application. Follow the suggested categories outlined in this paper to help you develop a detailed profile of your part. Once a profile is developed, it will become your blueprint for material selection.

**1. Product design and manufacturing lifecycle**

First, consider where you're at in the product design and manufacturing cycle. This is significant because the best materials for showing fine feature details aren't always the best materials for providing structural strength and vice-versa. If, for example, you are building an aesthetic part as a concept model to showcase at a trade show or prototype review meeting, then it just needs to look good. It probably doesn't matter as much whether it's dimensionally accurate or whether it has the mechanical integrity of a functional prototype for form, fit and function tests. If, on the other hand, you're further along in the product development cycle to the point where you're looking to produce an actual end-use part, material properties impacting mechanical properties and structural integrity are far more critical.




**2. Geometry**

Second, it's important to recognize that a part's design and geometry will have a greater impact on material choice for FDM than for injection molding. Due to this fact, make sure the detailed part profile you're outlining for material selection gives careful attention to geometric requirements such as:

- Contours – A contour is the material deposited along the perimeter curve of each layer of an FDM part. This deposited layer of material makes up the outer extents of each layer. By default, all models are built using a contour.
- Slice thickness – The height of each layer used to manufacture an FDM part.
- Wall thickness – The minimum wall thickness for FDM parts varies depending on the slice thickness that will be used to build the part.
- Features – FDM technology uses a special support material to hold overhanging geometry in place as the model is created. However, the model is considered self-supporting if it does not need additional supports when building. This is typical on slopes up to 45 degrees from vertical.
- Rasters – A raster is the material used to fill the interior of a layer. This extrusion can be set to fill the interior as solid or sparse. Additional adjustments can be made to fill with a negative air or positive air gap creating a custom density.

This is a good time to remind you that with FDM, there is virtually no limitation to the size of part you can produce. Plus, FDM can handle any geometry, no matter how complex. In fact, there are much greater cost and time advantages to additive manufacturing when parts have complex shapes. Soluble support materials used during the FDM build process make it possible to produce parts with cavities, overhangs, holes and sharp corners; whereas injection molding is limited in its ability to accommodate parts with such complex geometries. Additionally, FDM parts are not as susceptible to warping, so consistent wall thickness is not always required. Finally, FDM does not require the addition of deep ribs as would an injection molded part to accommodate its CNC approach to milling out the tooling material.

**3. Function**

Next, you need to consider the intended function of the part. Address the following questions:

- Will your part need to perform a mechanical function, such as bearing a load, stress or friction?
- Will your part be used in an industry, such as medical or aerospace, that has specific bio-compatibility or certified body requirements?
- What environment will the part live in?
- What tolerances will it require?

The material properties in the table on page 5 are typically measured for FDM and PolyJet materials.

Finally, note whether your part will be exposed to chemicals, water, humidity or extreme temperatures. Certain materials are formulated to endure exposure to heat, chemicals, humid or dry environments and mechanical stress, as well as those meeting certified body requirements. Some example materials include:

- ULTEM 9085 for ductwork and interior components in aerospace and automotive applications
- FDM Nylon 12 for high fatigue endurance, snap fits and friction-fit inserts in aerospace and automotive applications
- High Temperature PolyJet photopolymers for testing applications such as hot-air flow or hot-water flow in pipes and faucets

**4. Certifications**

Note whether your project or application requires use of a certified material – a common necessity in the aerospace, automotive and medical industries. There are several certified materials available for 3D printing. For example, ABS-M30i and PC-ISO for FDM are both ISO-10993 certified, which means they are medical grade materials that are biocompatible. ULTEM 9085 is FST-certified, which means the material fully complies with aircraft interior flame-smoke-toxicity regulations and aircraft manufacturers' toxicity requirements.

**5. Service life**

Finally, your part profile should note the ideal service life of the part, including the frequency of its use during that time period. For example, how many cycles will the part need to endure? As you know, some materials are more durable than others. Additionally, changes can be made to part design before build to help improve part performance from a durability perspective, so it's vital to note these requirements up-front so you can plan accordingly. In general, manufacturing tools (e.g. jigs and fixtures) tend to wear out fast because they undergo constant use in high-impact environments; whereas concept models and prototypes typically have a short service life.

## MATERIAL PROPERTIES

As with injection molding, materials used for 3D printing have different properties and limitations. For each material available, you will be able to consider various characteristics that might be important to your project, including those detailed in the chart below:

| MATERIAL PROPERTY | DEFINITION | TEST METHOD | MEASURED UNITS |
|---|---|---|---|
| **Mechanical Properties** | | | |
| Tensile strength | The ability to resist breaking under pressure.[1] | ASTM D638 | Psi or MPa |
| Tensile elongation | The percentage increase in length that occurs before a material breaks under tension.[1] | ASTM D638 | Percent |
| Tensile modulus | The ratio of stress to elastic strain in tension.[1] | ASTM D638 | Psi or MPa |
| Flexural strength | The ability to resist deformation under load.[2] | ASTM D790 | Psi or MPa |
| Flexural modulus | The ratio of stress to strain in flexural deformation.[2] | ASTM D790 | Psi or MPa |
| IZOD impact | The relative impact resistance tested with a notched and un-notched sample.[3] | ASTM D256 | ft-lb/in or J/m |
| **Thermal Properties** | | | |
| Heat deflection temperature (HDT) | A measure of a polymer or plastic's ability to bear a given load at elevated temperatures. FDM materials are measured at two common loads: 0.46 MPa (66 psi) and 1.8 MPa (264 psi).[4] | ASTM D648 | °F or °C |
| Glass transition (Tg) | The reversible transition in amorphous materials from a hard and relatively brittle state into a molten or rubber-like state.[5] | DSC (SSYS) | °F or °C |
| Coefficient of thermal expansion | The change in density that occurs as a material changes in temperature.[6] | ASTM E228 | E-05 in/in/°F or E-05 mm/mm/°C |
| **Electrical Properties** | | | |
| Volume resistivity | How strongly material opposes the flow of electric current.[7] | ASTM D257 | e15 ohms-cm |
| Dielectric constant | The ratio of the flux density produced by an electric field in a given dielectric.[8] | ASTM D150-98 | Flux density |
| Dissipation factor | The heat that is lost when an insulator is exposed to an alternating field of electricity.[9] | ASTM D150-98 | Dissipation range |
| Dielectric strength | Voltage at which the insulating qualities of a material break down.[10] | ASTM D149-09 | V/mil |
| **Other** | | | |
| Specific gravity | The ratio of the volume and weight of a substance to an equal volume and weight of water.[11] | ASTM D792 | Volume to weight |
| Flame classification | Flammability of plastic material.[12] | UL | HB or V-O |
| Rockwell hardness | The net increase in depth of impression as a load is applied.[13] | ASTM D785 | Scale M |
| Shore hardness | A measure of the resistance of material to indentation.[13] | Scale A - D | Scale A - D |
| **Photopolymer Specific** | | | |
| Water absorption | The rate of absorption of water.[14] | D-570-98 24-hr | Percent |
| Ash content | The amount of fillers or minerals in a material.[15] | USP281 | Percent |

## MATERIAL SELECTION FOR FDM

In order to select the proper material for your FDM project, you need to understand the capabilities and limitations of FDM technology. Fixtures, tools and prototypes made with FDM can withstand constant use on the production floor and perform well in punishing applications such as HVAC prototyping and auto racing. FDM materials offer specialized properties like toughness, electrostatic dissipation, biocompatibility, V-O flammability and FST ratings. Furthermore, FDM parts rival injection molded parts in mechanical, thermal and chemical strength. They can endure exposure to heat, chemicals, humid or dry environments, and mechanical stress. This makes them perfect for demanding applications and high standards in aerospace, automotive, medical and other industries. Types of materials available include:

**ABS Themoplastics**
ABS thermoplastics are strong, production-grade materials used across many industries in applications where impact-resistance and structural strength are necessary. They are accurate, durable and robust enough for field testing or demonstration units. With excellent dimensional stability, thermoplastics are a good fit for pre-production rapid prototypes that can accurately predict performance of production parts. There are also variations for high-requirement applications, such as ABS-M30i for ISO-10993 certified applications and ABS-ESD7 for static dissipative electronic components.

**Polycarbonates**
Polycarbonates are widely used in automotive, aerospace, medical and other applications. Polycarbonate offers accuracy, durability and stability, creating strong parts that withstand functional testing. It has a higher impact strength and can handle higher temperatures than ABS. Common applications include: form, fit, and function, concept modeling, snap-fits, vacuum metallization, electroplating, and as a master for RTV molding and vacuum forming.

**FST Certified**
ULTEM 9085 is ideal for aerospace, automotive and military applications because of its FST rating, high strength-to-weight ratio and existing certifications.

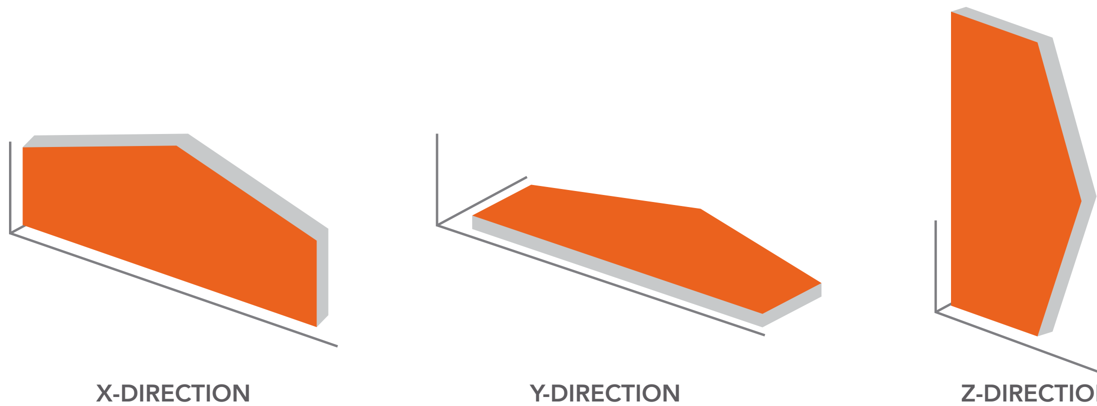
## FDM DESIGN CONSIDERATIONS

One of the most valuable insights we can offer you about material selection for FDM is to not let past "design for manufacturing" practices or traditions dictate future material decisions. Old-school thinking might limit potential benefits of new technologies. For example, as mentioned earlier, geometric design considerations – like using consistent wall thickness to prevent warp and the addition of deep ribs – that are necessary for injection molded parts do not apply to FDM parts. Additionally, there is no need to add shrink factors into part design. Shrink rates are automatically added to the part when the design file is processed.

**Design for additive manufacturability**
Here's just one example of the type of "new-school" thinking you can employ with 3D printing: A part previously made of sheet metal through injection molding may now be an ideal candidate for a plastic part produced by FDM, offering significant cost-savings because no tooling is required. In this case, you can actually design cost out of a part. This shift in your approach to design is what we at RedEye call design for additive manufacturability. If you take your existing parts and rethink design within the context of additive manufacturing, you may find some simple solutions to challenges or inherent structural support issues that currently exist.

**Build orientation**

Orientation of the part during printing can impact FDM build significantly and change the properties of a material. Orientation can be chosen to maximize build time, strength, material use and surface finish. Considerations need to be made for: build speed, surface quality or finish, strength, support removal and air flow. For example, a part built standing up may have thinner walls, making them more brittle, requiring design changes or a stronger material. Additionally, builds in the X direction typically obtain the best strength and elongation before break, whereas builds in the Y-direction accomplish lower strength values and builds in the Z-direction have the lowest tensile strength. However, keep in mind that a part's overall strength performance is geometry dependent.




In the context of orientation, be aware that you have options regarding the slice thickness of the build. In other words, you have some choices in the height of the bead of plastic material deposited by the printer tip, which can impact both the aesthetics and cost of the part. Thicker slices yield a less expensive build, but may be less aesthetically pleasing for some parts because you get a more noticeable layer lines or stepping effect in part contours. Whereas thinner slices are more expensive to build, but the aesthetic impact is less noticeable. You can orientate the build to minimize layer lines and stepping on the least critical surface and attempt to minimize build costs. Discuss your project objectives with a RedEye representative and he or she can help you determine which slice thickness is best for your part.

**Sectioning FDM parts**

As mentioned earlier, no part is too big to be built with FDM. Sectioning designs prior to manufacturing may be necessary to accommodate parts larger than 36 in. x 24 in. x 36 in. Sectioning can also be used to eliminate excess amounts of support structure or to protect fragile features that may be damaged during secondary operations. Once your sections are built, there are a number of bonding and welding methods that can be used to attach features and join sectioned parts.

**Fills**

One unique benefit of FDM is it allows you to build solid parts with a semi-hollow honeycomb interior. These parts have an excellent strength to weight ratio – one that is equivalent to a solid part. The difference, however, is these components can be as much as 65 percent lighter than traditional, subtractive manufacturing methods, which can have tremendous impact on weight, ergonomics, and ultimately fuel costs of the final product.

# MATERIAL SELECTION FOR POLYJET

PolyJet photopolymers combine a wide variety of material properties with thin layers, allowing you to create true product realism in your prototypes. The layers measure only 16 microns (0.0006 in.), resulting in a smooth surface finish. PolyJet gives you multi-material and multi-color flexibility, which means you can combine materials within the same 3D printed model or in the same print job. This enables applications such as over-molding, grayscale coloring, simultaneous prints in different materials, among others.

PolyJet is also the only 3D printing technology capable of building with rubber-like materials. This allows you to simulate rubber with different levels of hardness, elongation and tear resistance. These materials are ideal for concept models and prototypes in which the final product will be made of rubber, such as tires, handles, footwear and non-slip surfaces.

You can also combine up to three materials to create composite digital materials with very specific properties. From rubber-like in different Shore scale A values to polypropylene- and ABS-like simulation, it's possible to combine both opaque and transparent as well as both rigid and soft touch elements into the same part. There are more than 100 digital material combinations, making it possible for prototypes to simulate the look, feel and function of the most complex end products. The PolyJet material families include:

### Digital materials

Digital materials can be combined in specific concentrations and structures to form desired mechanical and visual properties.

### High temperature and ABS-like

The high temperature and ABS-like photopolymers simulate the thermal performance of standard plastics and are ideal for thermal testing of static parts.

### Transparent

Transparent PolyJet materials are semi-translucent photopolymers for standard clear plastics simulation.

### Rigid opaque

Rigid opaque photopolymers provide excellent detail for durable prototypes and form, fit and function tests.

### Polypropylene-like

Polypropylene-like materials allow you to print prototypes that provide the appearance, flexibility, strength and toughness of real polypropylene.

### Rubber-like

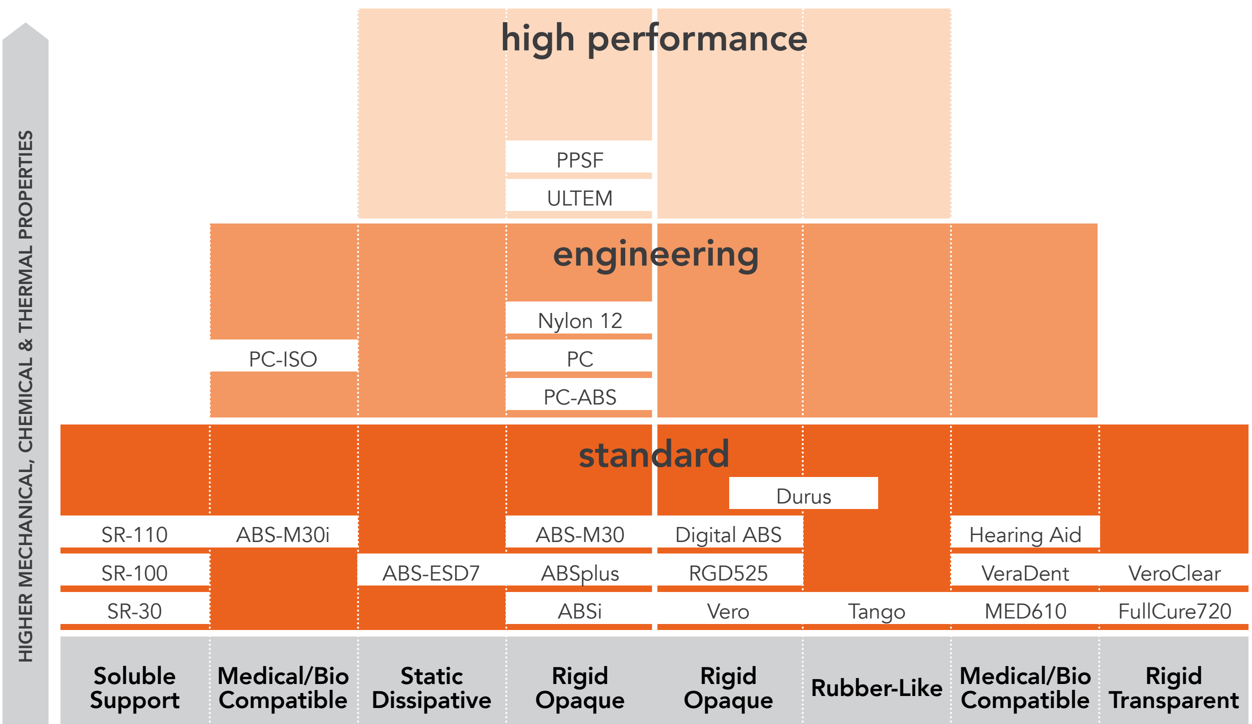
Rubber-like PolyJet photopolymers allow you to simulate rubber with different levels of hardness, elongation and tear resistance.

### Medical

PolyJet's family of medical materials offer excellent visualization and dimensional stability, and are bio-compatible for dental products, surgical guides and hearing aids.

## POLYJET DESIGN CONSIDERATIONS

It's important to note that photopolymers change with exposure to light and therefore do not age as well as engineering thermoplastics. Keep this in mind if you are considering PolyJet for an end-use application. Because of their service life, PolyJet materials are best suited for concept models and prototypes with fine feature details. With their ability to achieve a smooth surface, PolyJet materials are also ideal for creating injection molding tools for prototyping or even short runs. You can quickly create custom injection molds to produce low volumes of parts in the final production plastic, saving time and money on tooling. PolyJet is a good method for prototyping injection molds when there are complex geometries, when you are producing low quantities, if design changes are likely and if there are time constraints.




### FDM

Subject 3D printed parts to tight tolerances, tough testing and harsh environments with FDM materials.

- Real thermoplastics
- Advanced functional performance
- Strong, tough & durable
- Stable over time
- Economical

### POLYJET

PolyJet technology uses the widest variety of materials and multiple materials in one build.

- Simulated plastics & elastomers
- Prototyping versatility
- Dual material jetting
- High precision, fine detail accuracy
- Surface smoothness
- Digital blends for endless possibilities

## FINISHING CONSIDERATIONS

At the outset of material selection for your project, you need to think about whether you would like to employ any secondary finishes to your part after it's printed. For example, if you're going for a glass-like surface instead of the natural layer lines of an FDM-printed part or if you plan to prime or paint the part, then your project will involve some type of secondary finishing. Options range from tumbling to vapor smoothing to bead blasting, buffing and plating, among others. You need to determine your desire to pursue finishing up-front because the material properties of FDM and PolyJet parts can change after secondary operations. If you tumble or sand the part, for example, you'll likely lose some material, affecting accuracy and strength. Knowing this in advance, allows you to modify the part's design to accommodate finishing without compromising strength or accuracy.

## MAKING YOUR MATERIAL SELECTION

By now, you should have a deeper understanding of the multiple facets to consider when selecting a material for your next 3D printed project. To summarize, the most successful projects are those that consider the part's intended use, the environment in which it will be used, the desired aesthetic and the capabilities and limitations of the technology you will use to print the part. Follow the suggestions in this paper to develop a detailed profile for your part. Then, consult with the experts at RedEye to discuss your project and help you determine the right material for the job. For a detailed list of the materials offered by RedEye for FDM and PolyJet technologies, visit http://www.redeyeondemand.com/rapid-prototype-materials.

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