
# The Ultimate Guide to Material Selection for Serial Production with Selective Laser Sintering

Essential Knowledge Briefings

PLASTICS ENGINEERING
AN OFFICIAL PUBLICATION OF SPE

spe INSPIRING PLASTICS PROFESSIONALS

Sponsored by:

3D SYSTEMS

Cover Image: Courtesy of 3D Systems, Inc.

# CONTENTS

# INTRODUCTION

About 40 years ago, additive manufacturing—known more commonly as 3D printing—planted the seeds of a manufacturing revolution.

It began by offering engineers and designers of industrial and consumer parts the ability to rapidly create unlimited iterations of part concept prototypes by building them layer by layer from resin or powder.

From there, attention has turned to producing relatively small batches of high-value parts that were difficult or impossible to manufacture with traditional methods. The complex geometries capable with 3D printing offer unprecedented design flexibility without the need for expensive tooling.

Design engineers have a wide array of 3D printing methods to choose from, utilizing various plastics and metals and even full-color materials. These methods fuse materials in various ways—for example, by exposing liquid resin to UV light (photopolymerization), heated and extruded plastic filament, inkjet style printing, and melting or sintering of plastic or metal powders. Some printer technologies require binding agents to join the layers.

Selective laser sintering (SLS) is one of the earliest methods of digital direct thermoplastic manufacturing. Using a high-powered $CO_2$ laser, SLS sinters powdered nylon and other plastics into three-dimensional parts one layer at a time from a bed of powder scanned by the beam. Each layer is based on 3D data from a CAD (computer-aided design) file transposed into 2D cross-sections for each layer. SLS powders generally have a diameter of less than 100 µm, facilitating their fusion by the laser beam.

Freed from constraints by, say, an injection mold, engineers can test design after design after design using additive manufacturing, tweaking features as often as they desire, simply by modifying data in the CAD software.

Being able to refine and print new part features in hours instead of days, without the expense of creating a new mold for each iteration, lets manufacturers optimize products quickly, test and validate more designs, and bring them to market much faster.

As 3D printers evolve, so too do the materials used to make parts and prototypes. As design engineers explore more novel solutions to traditional components—particularly by consolidating multiple parts of an assembly into a single monolithic part—materials are being refined to meet very specific performance requirements like heat resistance, impact strength, and varying degrees of rigidity or flexibility. To ensure those materials perform exactly as expected with each and every "build," technology providers qualify those materials on their printers to verify that a given combination of material and machine will produce parts that perform consistently.

In its three-decade history, SLS has been embraced by multiple industries for far more than just producing rapid prototypes. Functioning parts and products ranging in size from clips to air ducts for aircraft are being produced in increasing numbers—from a handful to thousands. Thanks to the precision of SLS, part tolerances are extremely tight, and enable highly complex geometries to be produced.

When it comes to running a manufacturing business, a robust SLS process must be able to stand shoulder to shoulder with other manufacturing methods in quickly turning out consistent, repeatable parts in sufficient quantities.

SLS is particularly attractive vis-à-vis injection molding in cases where the latter is far too cost-prohibitive or incapable of producing the uniquely complex parts at which 3D printing excels. While injection molding remains an ideal choice for producing hundreds of thousands or millions of relatively commonplace parts, SLS can produce mass custom parts of extraordinary quality and with performance characteristics like high durability, low weight, and as single-build parts not requiring assembly.

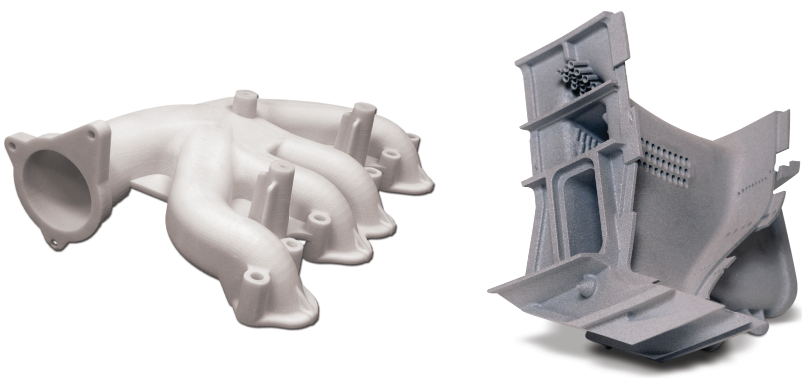
Ultimately, the sky is the limit for the types of parts that can be additively produced. 3D printed parts excel in a broad array of applications, from medical and dental to aviation and consumer goods—even in harsh and demanding environments from professional auto racing to the International Space Station.

**Selective laser sintering (SLS), an early method for digital direct additive manufacturing, can be used to produce a wide array of objects and parts.**

Source: Image courtesy of 3D Systems, Inc.

Optimizing SLS for serial part production requires not just material selection but careful consideration of how material, machine, and software work together. Some technology providers have amassed decades of knowledge in process design to help designers and manufacturers proceed from initial part designs to serial production. Following are some guiding principles to help design engineers navigate key decisions when using SLS for serial production.

Collage of various print samples with SLS:



**Additive manufacturing enables a new design approach that is not limited by traditional manufacturing constraints**

Source: Image courtesy of 3D Systems, Inc.

# DESIGN CONSIDERATIONS FOR SERIAL PRODUCTION APPLICATIONS USING SLS

Designing a part for serial SLS production requires a completely different thought process than for subtractive or formative manufacturing—starting with the idea that cost and complexity have no correlation in SLS additive manufacturing and can sometimes be inversely proportional. SLS becomes a clear choice over injection molding for a broad array of parts upon a closer look at the nature of each process.

**3D printing can be used to seamlessly produce integrated moving parts like sockets, joints, and hinges.**

Source: Image courtesy of 3D Systems, Inc.

While ideal for very high volumes of relative simple shapes, injection molding can be prohibitively expensive and unwarranted for lower part volumes. Each mold is a highly complex part in itself, requiring significant engineering and multiple moving parts. And if engineers want to change part design after running a small batch of parts, they must design and produce an entirely new mold—which can be expensive. A typical injection mold might cost between $4,500 and $16,000, about the price of some desktop 3D printers for rapid prototyping. While a simpler single-cavity mold might cost less—closer to $2,000—larger, more complex high-production molds can easily run $100,000 or more.

SLS, of course, allows near-infinite customization and on-the-fly design tweaking. Designers can quickly produce as many versions of parts as they can CAD files. They can condense a multipart molded assembly into a single 3D-printed part, eliminating the quality issues and labor costs that can arise from assembling multiple components.

Engineers can even print moving features inside stationary features with SLS. Duct work, brackets, and integrated locking mechanisms can be seamlessly integrated into the overall design. SLS is particularly useful for integrated living hinges, bendable parts, and integrated joints within a single-build part design.

That stands in sharp contrast to molding a part, the design of which must be produced in two halves and under severe design limitations: there can be no undercuts that prevent the mold from opening, draft angles have to be exact, ribs demand very specific dimensions, and wall thicknesses have to remain constant.

To optimize part designs and take advantage of the unique flexibility and cost benefits of SLS, engineers should ask technology providers some key questions:

- What material and machine parameters are optimum to achieve the performance characteristics and esthetics required of the finished part?
- How will the technology provider benchmark material performance through the 3D printers that will be used for serial production?
- How much experience does the technology provider have with complete process design for SLS that optimizes the interaction of software, materials, and machines to produce consistent parts from build to build?
- What level of institutional knowledge of SLS part design can the technology provider demonstrate through resources such as data sheets, documented case studies, etc.?

Once those questions are answered, designers can move forward on creating designs that would be impossible to mold but straightforward to 3D print. Unconstrained by injection molding rules for design and material selection, engineers can incorporate just about any conceivable geometries that support the overall part design. For instance, a rib can be located at the center or edge of a panel depending on how much of a load the panel is expected to endure. For weight reduction, a rib can be printed in a hollow lattice structure.

Likewise, constant wall thicknesses are not required for SLS parts. Wall thicknesses can be varied throughout the part for various impact scenarios—for instance, a grain feed tube which is thicker at the top where the greater impact resides, and thinner at the bend.

Designing for function is the ultimate value proposition SLS offers. In a traditional formative or subtractive process, an engineer working on Part A might want to impact significant stiffness by designing it with 100 ribs and a double wall with corrugation in between. Molding the part likely would be so expensive that the engineer would have to compromise functionality to make it economical to fabricate. But SLS reboots that entire philosophy. In some instances, adding design complexity—e.g., hollowing a part or making it tubular—helps reduce part cost.

Consider a part that might be made hollow and reinforced with webbing. With traditional manufacturing design, all those features must be expressed in the tooling. In such a case, there is a close relationship between design complexity and increased cost. But with SLS, there is very little correlation. Complexity in a 3D-printed part can save money not only in the manufacturing stage but also throughout the life cycle of the part, as printed parts can be lighter, better designed, and higher performing.

Also informing the design of SLS parts is the familiar engineering concept of design allowables—the thorough understanding of a material's capabilities so engineers can design parts to prevent any possibility of failure. Designing with SLS nylons is no different than designing with materials for traditional manufacturing. Ideally armed with extensive performance, data provided by the material supplier, engineers must further quantify and qualify that material's performance on a given machine for a desired part, based on "off-the-shelf" testing methodology outlined in ASTM standards.

It is worth noting that about 80% of CAD files that are SLS printed for production workflows were originally designed for injection molding. However, the part volume was ultimately so low it was impossible to justify injection molding to produce them. In fact, in most cases, when a design engineer runs a CAD file that was designed for injection molding through a 3D printer, the per-part cost is more expensive. That can create what some experts call a "false negative" with respect to understanding the value proposition of additive manufacturing.

A part designed for SLS from the outset realizes the full potential of additive manufacturing. So, instead of a component made from 100 plastic parts that must be assembled, SLS can produce a single part that requires no added assembly labor, eliminates multiple potential failure points, requires fewer vendors, streamlines the supply chain, and produces an overall better product.

Examples of parts that ideally lend themselves to SLS production include the following:

- 100 plastics clips for a Formula 1 race car.
- 50 experimental test cups for the International Space Station.
- 10 air ducts or 15 electronic enclosures for an F/A-18 Super Hornet jet fighter.
- Five air ducts for a unmanned combat air vehicle (UCAV).

Dividing the cost of the tooling to make such parts by the scant quantity produced illustrates how expensive those parts become to make without SLS.

Therefore, low-volume, high-value production with commodity thermoplastics is the primary target application for SLS.

With those concepts in mind, here are some common part designs, features, and material considerations for each:

- **Axles:** Designers can manage friction by applying 1–2 mm rails on the static "not stressed" side of the assembly. Keep clearance between the rails axle tube at 0.3 mm. In regions away from the rails, a clearance of 2 mm or more will enable complete and easy powder removal by blowing compressed air through the powder-removal access ports modeled into the static side. Remove powder from the axle cavity by rotating and applying pressurized air in tandem.
- **Aztec barcodes:** With these features, engineers should make the cells < 1 mm cubed and apply contrast ink to the raised surfaces, to enable or accelerate image captured by a scanner.
- **Bellows:** Designers can incorporate functional "bellows" sections for applications where some flexibility is required in assembly or coupling. Note that nylon performs poorly in applications requiring repetitive cycling, such as wire and hose shrouding in mechanisms. Only consider applications where parts will be exposed to very low frequency flex cycling.
- **Complex ducting/webbing:** For nonstructural, low-volume ducting—such as Environmental Control Systems ducting for aerospace and performance racing—SLS allows highly optimized, very complex single-piece structures that do not need assembly. Engineers can design variable wall thicknesses and increase strength-to-weight ratio with structurally optimized surface webbing.

- **Lattice structures:** SLS machines can fabricate lattice structures down to almost 0.5 mm in diameter, reducing weight on the part and minimizing material usage.
- **Tanks:** A correctly sintered SLS nylon tank (density >0.98 g/cc with a wall thickness of >1 mm) is capable of holding a liquid or a gas under pressure.

## CASE STUDY 1

*To illustrate the design flexibility and production-grade parts afforded by SLS and the right materials, consider Idaho Steel, a machine manufacturer.*

*Idaho Steel fabricates machines for food processing—namely for rendering potatoes in an almost infinite variety of shapes and sizes. The company's focus on customization to meet customer needs made SLS 3D printing a perfect fit.*

One of Idaho Steel's prime applications for 3D printing is customizing forming inserts and pistons for its Nex-Gem Former machine that forms potato products in different shapes. The forming inserts and pistons were formerly made from five parts, machined out of plastic and held together with 25 or more fasteners. Using multiple CNC operations and manual assembly, it took up to 250 hours—25 work days—to complete a set of 16 forming pistons.

Idaho Steel now makes the same number of parts in 90 hours of virtually unattended, continuous run-time on the ProX 500 machine, with the five parts of the assembly reduced down to a single part.

The forming insert and piston are made by the SLS 3D printer as a complete, single assembly using 3D Systems's food-safe DuraForm ProX material. The "one-part" approach with no fasteners further enables the designers to remove harborage areas and eliminate potential contamination risks that fasteners can bring.

**Products that needed assembly using multiple parts can now be reduced to a single part thanks to selective laser sintering.**

Source: Image courtesy of 3D Systems, Inc.

## MATERIAL CONSIDERATIONS FOR SERIAL PRODUCTION APPLICATIONS USING SLS

SLS uses nylon and other thermoplastics which can have added materials to produce a range of plastics for multiple performance and color requirements. Contrast that with alternative thermoplastic additive methods that can diminish final part performance or esthetics. For instance, binder jet printing requires the addition of binder material mixed with nylon to fuse each layer. Fused deposition modeling, a slower printing process than SLS, fuses thermoplastic filament and results in a part that appears ridged because each printed layer shows and often demonstrates part weakness through the fusing process.

Nylons for SLS are generally familiar to design engineers. Tough-yet-flexible PA 11, the workhorse PA 12, and their various derivatives have been industry standards for injection molding. 3D printer suppliers will continue to expand their material portfolios to add functionality that echoes the multiple composite blends available for traditional manufacturing.

These materials might be reinforced with aluminum, glass beads, and mineral, or fiber materials.

Compare the following options for a standard nylon 12 material reinforced with a variety of glass beads. Pure nylon 12 could be filled with 50% solid glass bead versus 40% hollow glass bead. While the part produced with the latter loses some strength, it is also considerably lighter than the part featuring solid glass bead material. For nonstructural parts produced for use in NASCAR or Formula 1 auto racing, for instance, that lightweighting is clearly a critical advantage. Glass beads, solid or hollow, will also improve some of the mechanical properties of nylon 12, demonstrating greater heat deflection temperature (HDT) and more rigidity. They are generally heavier than the pure, or unfilled, nylons.

Using mineral fiber-filled material would provide still other characteristics. Some of the fiber-filled materials improve strength and modulus properties while limiting weight increase.

Other specialty products include polystyrene SLS for investment casting, in which the material is used to build a pattern that is burned away for the creation of metal components.

Some SLS materials are capable of meeting the requirements of ISO 10993-01, USP Class VI, food handling, and flame retardancy certifications for aerospace and are resistant to fluids such as diesel, ethanol, freon, mineral oil, motor oils, gasoline, and more.

Regardless of part design, designers also have to take into account how different powders act when sintered. SLS allows for a variety of materials to be used. The materials may react differently depending on the settings and tolerances of the printer, the blend of fresh to recycled powder, and if the material has a filler such as glass beads, carbon fibers, aluminum particles, etc. This is true even for the different types of nylon.

This variability is one area how 3D printing differs from injection molding, where pouring the same material into various makes and models of injection molders will produce the same part as long as the proper melt conditions are maintained.

Material data sheets are critical to outline the expected ranges of parameters for the sintered materials, but they are only rough guides. Therefore, designers, engineers, and part manufacturers will need to work with suppliers to align the material mechanical properties to the target applications.

Often, engineers are seeking an SLS-printed solution to a part that was previously produced with a traditional method like injection molding for a number of years—and they want to use the same material they have been using. At the same time, they acknowledge that they will evolve into manufacturing more with SLS. While the material they end up using to replace a traditional process with SLS might not be an exact match, it can be dialed in precisely through collaboration with the material supplier.

For engineers to choose the right material(s) for SLS parts, they must ask themselves some key questions:

- How durable must the part be?
- What other properties might be important? —Strength, thermal resistance, rigidity, weight, density?
- What esthetics are essential for the finished part?
- Does the material supplier offer a database of materials characterized for specific production and performance attributes?
- Is this material qualified for current and legacy machines? Will it be?
- What services and guidance will be provided during the material procurement and process design stages?
- Does the material supplier also make software to optimize the use of its materials and/or machines?

To ensure final parts perform as planned, SLS materials are often called upon to provide superior impact strength, elongation at break, heat resistance, and load bearing capacity. High-performing materials should offer properties in the neighborhood of the following measurements:

- **Impact resistance:** More than 45 J/m on impact in drop dart testing compared with injection molded ABS plastic.
- **Elongation at break:** 47%, with flexural strength of 46 MPa/psi to enable multiple bends without tearing.
- **Heat resistance:** Ideal HDT of 179 °C at 1.82 MPa.
- **Load bearing:** Shore D hardness of 73, ultimate tensile strength of 48–51 MPa, and an unnotched Izod impact strength of 310 J/m.

| | Density sintered part (g/cm³) | Flexural modulus (MPa) | Flexural strength (MPa) | Tensile modulus (MPa) | Tensile strength (MPa) | Elongation at break (%) | Impact strength (J/m) Notched Izod | Impact strength (J/m) Unnotched Izod | Heat deflection temperature (°C) @0.45 MPa | Heat deflection temperature (°C) @1.82 MPa | Flammability | Hardness |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | ASTM 792 | ASTM D790 | ASTM D790 | ASTM D638 | ASTM D638 | ASTM D638 | ASTM D256 | ASTM D256 | ASTM D648 | ASTM D648 | UL 94 | ASTM D2240 |
| *ProX compatible material properties* | | | | | | | | | | | | |
| DuraForm ProX PA | 0.95 | 1650 | 63 | 1770 | 47 | 22 | 45 | 644 | 182 | 97 | HB | 73D |
| DuraForm ProX GF | 1.33 | 3120 | 60 | 3720 | 45 | 2.8 | 48 | 207 | 180 | 129 | HB | 73D |
| DuraForm ProX HST | 1.12 | 3430 | 75 | 4123 | 44 | 4.3 | 55 | 307 | 183 | 171 | HB | 73D |
| DuraForm ProX EX BLK | 1.02 | 1360 | 51 | 1570 | 43 | 60[a] | 75 | 3336 | 193 | 57 | HB | 76D |
| DuraForm ProX EX NAT | 1.02 | 1436 | 56 | 1590 | 51 | 61[a] | 91 | Did not break | 192 | 56 | HB | 77D |
| DuraForm ProX AF+ | 1.31 | 3710 | 64 | 4340 | 37 | 3 | 54 | 255 | 182 | 174 | HB | 78D |
| DuraForm ProX FR1200 | 1.03 | 1720 | 61 | 2010 | 45 | 8 | 24 | 278 | 180 | 94 | HB | 77D |

[a] XY orientation at 5 mm/min.

If chemical resistance is an issue, materials should be tested to demonstrate that they can withstand the ill effects of substances that the part may come into contact with alkalis, organic solvents, petroleum products, oils, fats, aromatic and aliphatic hydrocarbons, ketones, and esters. Material manufacturers can and should provide guidelines on suitability of various SLS materials exposed to a range of chemicals.

## BEST PRACTICES FOR MANAGING CONSISTENCY PART TO PART AND BUILD TO BUILD USING SLS

Serial production of functional parts with SLS has become an established tool thanks to repeatability built upon about three decades' worth of process knowledge. Achieving that repeatability requires careful consideration for and execution of some vital steps.

The first step is to benchmark each 3D printer and material to understand firstly how a given material will perform in that machine and also to prove that the printer and material will continue to produce exactly the results desired.

Another benchmark to perform is understanding of how different SLS materials might perform differently over the life of a part. Filled materials, for instance, might react differently than pure nylons.

Other than some mild changes in color—unless the part was post-processed, such as being painted—SLS nylons retain most of their mechanical properties over time. Depending on material type and application, SLS is considered to exhibit limited creep.

Quality assurance measures on the part of the material supplier are equally crucial to ensuring engineers are selecting from the most optimal materials for contemporary SLS printers.

Part-to-part quality control best practices are essentially the same as those for traditional manufacturing. To guarantee a part meets a certain specification in terms of accuracy and mechanical properties, process and quality control must be implemented.

The primary control mechanism to ensure near 100% confidence in the final part is measuring and sampling. Tolerance requirements will dictate how often parts are measured, whether 10% of the time or 100% of the time—the latter being more likely for a high-risk application like a medical component. Measured samples can be pulled from the top, center, or bottom of a given batch of parts. For end-use part inspection and quality control, traditional devices like calipers, micrometers, coordinate measuring machines, and fit gauges, as well as noncontact 3D inspection through software, are all equally applicable to SLS production.

In some cases, it might be desirable to print a test part with other parts in a build and destructively examine the sacrificial part to ensure it—and the other parts—meets specifications.

But more unique to SLS and 3D printing in general are two more key variables to control to ensure repeatable parts: material blend ratios and machinery.

- **Proper blend:** Once a material blend ratio is established for a particular application, that ratio must be repeated for every build to maintain the accuracy of finished parts. If a material blend is drastically altered, then that change would require verification of key printing parameters still producing desired results in the final parts.

For instance, if a user is using a hypothetical material blend of 70% recycled powder and 30% fresh powder, continuing to use that blend will result in consistent parts given the process setup. Material and machine suppliers must assist the 3D printing managers in establishing sound, repeatable powder handling procedures to ensure consistency and control costs.

Manufacturers of high-value parts in highly regulated industries like medical or aerospace may favor a blend with far more fresh powder, resulting in higher part cost but vastly reducing risk of part failure. A “one-stop shop” fabricator, on the other hand, might use a higher amount of recycled powder in a less sensitive application, reducing per-part cost.

Automated material quality control technology has become available to feed recycled powder through a sieve before it is blended with fresh powder at the optimal ratio and then spread evenly throughout the build. Such systems also track and retain data for each powder batch, including blend ratio and lot number.

- **Equipment maintenance:** Keeping your printer in good functioning condition, with lasers and scanners calibrated within acceptable ranges, will help to ensure the highest quality parts.

Tuning your printer with strict attention to a part's build parameters is paramount to yield predictable dimensions and end-use properties. Consistent esthetics and dimensions, improved strength, and true-to-CAD accuracy all hinge upon the intricate interplay of machine, material, software, and supplier service.

The most knowledgeable technology suppliers will maintain a database of process control statistics, recording large amounts of machine and material performance information to indicate the robustness and repeatability of a given SLS application.

# BEST PRACTICES FOR ENSURING END-USE PART PERFORMANCE

Serial production with SLS has opened an exciting new world of novel parts possessing complex geometries that are impossible to design and build with traditional manufacturing methods.

From aviation and medicine to food and footwear, industries of all types are taking advantage of the cost-saving design complexity SLS offers. A startlingly varied array of applications can benefit from the excellent tensile strength, elongation, density, and modulus of SLS nylons. A rapidly expanding repertoire of robust, efficient, cost-effective, and customized parts created with SLS continues to inspire engineers to discover new ways to make use of this technology. Examples of just a few of the many ways brand owners have embraced SLS for serial production include the following groundbreaking solutions that exhibit the broad range of nylon material performance capabilities:

**Custom footwear:** 3D-printed insoles by Wiivv Wearables are biomechanically optimized for individual wearers. Photographs of customers' feet are rendered into data points with proprietary image processing software before being converted to printable SLS files. Having sold thousands of these individualized athletic shoe insoles, Wiivv launched a line of custom-fitted sandals with similarly customized arch support.

**These 3D-printed insoles from Wiivv Wearables are one example of customized products designed, developed, and created using additive manufacturing.**

Source: Image courtesy of 3D Systems, Inc.

**Aviation:** SLS printing is streamlining the creation or assembly of aircraft components inside and outside the plane. To reduce the time its air fleet spent on the ground for repair, one airline began printing replacement parts for in-cabin components using a flame-retardant material that was also 10% lighter than average aviation plastic. An aerospace manufacturer has saved 25 to 30 gallons of fuel an hour, as well as significant engine wear, on civilian and military aircraft by printing unique sets of microvanes that are attached to aft cargo doors to reduce drag. And another aerospace company significantly streamlined its assembly of panels to airframes by creating thermoplastic jigs that enabled faster production.

**Medicine and dentistry:** The orthopedic braces printed by UNYQ are a lightweight, breathable, and more esthetic solution to the traditionally bulky devices used to treat scoliosis or spinal curvature. And patient-specific surgical guides—many printed in-house at care facilities—assist medical professionals in properly placing thousands of unique implants with precisely guided incisions.

**Medical devices like this arm brace made from DuraForm PA are another example of customized items produced with additive manufacturing.**

Source: Image courtesy of 3D Systems, Inc.

**Welding fixtures:** Heat-resistant nylons that remain stable throughout the pressure, motion, and force of TIG welding allowed Rapid Application Group to create fixtures that were lighter and cost less to produce than traditional fixtures.

**Food processing:** SLS nylons certified for food contact enabled a manufacturer of food processing equipment to dramatically reduce the 250 hours it previously took to produce sets of forming inserts and pistons for a potato processing machine. SLS allowed Idaho Steel to reduce production time for each set of 16 inserts and pistons to 94 hours by eliminating the assembly of five separately machined plastic parts. Those parts required 25 or more fasteners, which are a known risk for retaining bacterial contamination; the food-safe SLS material improved sanitation as well as process efficiency.

Achieving these results requires adherence to some best practices that help ensure end-use parts exhibit the intended performance requirements. Not all SLS parts or products require either destructive or nondestructive testing. But in every validated industry or vertical market—medical and aerospace chief among them—such testing is most often required.

For such critical parts, having samples to test ensures that mechanical properties and other characteristics demonstrate the necessary performance characteristics and will pass certification requirements.

Those samples are mostly commonly created in the form of tensile bars, which are designed into the part build and tested after parts are printed. Density cubes are another type of sample.

Samples for testing can be printed at the beginning, middle, and end of a part build or otherwise inserted randomly as users wish. If those samples pass mechanical property tests after being printed, it can be assumed that the actual parts from that build possess the same characteristics.

A common method for studying materials is a tensile test, in which a machine pulls a sample bar from both ends simultaneously until it snaps. This method determines elongation at yield, elongation at break, tensile strength, and tensile modulus of the sample.

A key element to the stability and repeatability of SLS is the fact that it is a closed-loop thermal process, which allows for maintaining a consistent, controlled environment. During a build, infrared sensors in the printer measure temperature at the part bed. This has helped SLS mature past visual monitoring to lights-out production.

Data capture of process control statistics is another vital tool that has refined SLS processes. Current printers feature IR sensors that gather a wealth of information that details exactly how those machines perform. In addition to set points and actual temperature readings, contemporary printers monitor and record process-critical data measuring current draw and heater duty cycle. This information is used to maintain printers in optimal running condition, which contributes to the stability of nylon powders by warning production engineers if the printer exceeds those parameters.

Such data becomes useful, for instance, in the case of maintaining a sound process with a powder that has been overly used and not recycled or heated properly. To maintain mechanical properties in that instance would require increasing the duty cycle of the printer's main heater. Maintaining the heater at a lower duty cycle would maintain the set point but be too low to obtain the same melt effect.

By calculating material design allowables, monitoring machine data, and creating and testing tensile bars to ensure consistent final-part performance, design engineers can rapidly produce robust, geometrically complex parts that match or surpass injection molded components in function.

# CONCLUSION

As more industrial parts are made with SLS, reaching part-to-part consistency at serial production levels will require even more careful management of machine, material, software, and partner services.

Technology providers with the most experience in optimizing SLS are creating and qualifying materials specifically for contemporary 3D printers utilizing $CO_2$ lasers. Working closely with a new generation of design engineers who are increasingly well-versed in additive manufacturing flexibility, technology providers have become key sources of knowledge in collaborating on parts that are manufactured for design—not designed for a manufacturing process. In fact, they are amassing growing databases documenting SLS material performance attributes to assist engineers in choosing the right materials for certain parts and part features.

Ultimately, serial production of parts with SLS is offering an entirely new business case for 3D printing, lowering R&D and tooling costs while offering the ability to get parts to market faster than traditional formative or subtractive manufacturing.

## FURTHER READING

The New World of Thermoplastic Manufacturing with 3D Systems, 3D Systems, 2019.

## 3D SYSTEMS HISTORY

In 1983, Charles “Chuck” Hull invented stereolithography and produced the first 3D-printed part. He filed his patent for a stereolithography apparatus (SLA) in 1984, and two years later, co-founded the world’s first 3D printing company: 3D Systems.

The company commercialized the first SLA printer in 1987.

Since then, 3D Systems has evolved into provider of complete additive manufacturing solutions, offering a broad array of machines, materials, services, and software for multiple additive and engineering processes.

In 1996, 3D Systems began bringing MultiJet printers to the market and in 2001 added Selective Laser Sintering to its portfolio. Starting in 2009, 3D Systems began offering on-demand parts manufacturing; and subsequently added ColorJet printers, Direct Metal Printers and a suite of software for scanning, design, manufacturing and inspection. With the introduction of its Figure 4 system in 2016, 3D Systems again raised the bar on 3D printing performance.

Supporting those innovations are dozens of plastic, metal, color, dental, and metal casting materials engineered specifically by 3D Systems to support its portfolio of printing machines and production methodologies.

Front cover image courtesy of 3D Systems, Inc.

Essential Knowledge Briefings

WILEY

Sponsored by:

3D SYSTEMS