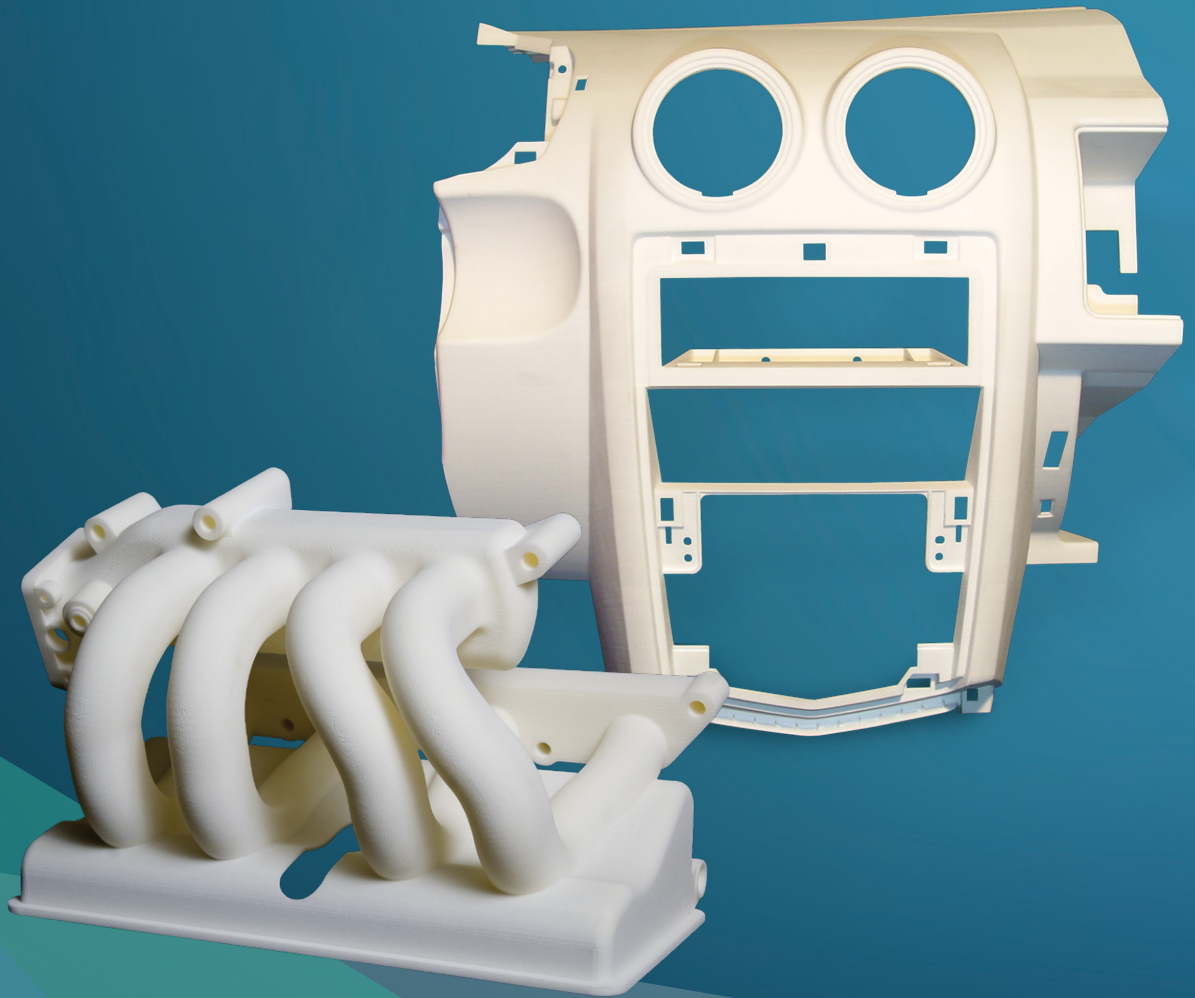


White Paper

The New World of Thermoplastic Manufacturing



Car makers are rewriting the rules of injection molding with 3D Systems thermoplastic additive manufacturing printers and materials.

Selective laser sintering (SLS) technology is at the heart of a growing trend in functional prototyping as well as mass custom manufacturing. For car makers, access to the right additive technologies, materials, and finishes are transforming manufacturing.

Direct digital manufacturing with thermoplastics offers exceptional quality while opening the door to new design parameters not possible with injection molding. Thermoplastic additive manufacturing also bypasses

the long lead time and up-front investment in injection molding tooling. If finished parts are measured in terms of quality, time to market, and cost per cubic inch, in many situations industrial SLS offers a better total value proposition.

3D Systems offers a wide variety of 3D printable thermoplastics, engineered for a range of applications that can withstand and excel under the rigorous demands and strains of automotive engineering and manufacturing.

3D printing offers a new avenue for materials specialists, designers, and manufacturing engineers to collaborate on getting the exact features they need for both aesthetics and function. These new design and manufacturing options open the door to improved products, new designs, new business models, and new markets. The key is knowing when to use thermoplastic additive manufacturing instead of conventional injection molding.

How selective laser sintering works

SLS is an additive process that uses a high-powered CO₂ laser to fuse small particles of powdered material (frequently nylon) to form three-dimensional parts. The part is built one layer at a time, using 3D CAD data.

A major benefit of the SLS additive process is that it does not require tooling to make parts, enabling mass custom manufacturing processes to be implemented at an affordable cost.

SLS parts can be designed with part consolidation in mind, eliminating assembly processes common to traditional manufacturing. Engineers can now design geometries for production — including living hinges and moving parts — that no other technology can produce, saving time and money in production.

SLS tolerances are incredibly tight. For X/Y planes tolerances are +/- .005". For the Z plane, the tolerance is +/- .010" for the first inch, plus +/- .005" for every inch thereafter. Such tight tolerances allow for highly complex geometries. The materials are durable and highly resistant to heat, chemicals, and impact.



Why choose SLS?

DuraForm® SLS materials from 3D Systems are delivered in many forms, including pure nylon 11 and nylon 12, both optimized and tolerance-controlled for use with 3D Systems printers.

For even greater engineered, end-use part performance, 3D Systems has developed DuraForm SLS materials with fillers such as glass, aluminum, and mineral fiber. Some SLS materials are also compliant with certifications for USP Class VI, food handling, and flame retardancy for aerospace. Many are likewise resistant to fluids such as diesel, ethanol, freon, mineral oil, motor oils, gasoline and more. DuraForm

SLS materials deliver on high tensile strengths, high heat resistance, and are suitable for use in harsh environments.

The bottom line is this: when you compare material properties, you'll find DuraForm SLS materials compare very favorably with common injection molding materials.

DuraForm materials are ideal for both production and prototype parts. For production, DuraForm SLS materials are a common replacement for ABS and polypropylene injection molded parts, especially in scenarios of mass custom manufacturing where traditional manufacturing processes are costly and

slow. Functional prototypes such as crash testing for helmets and car seats, on-engine parts for air and fluid flow, living hinge designs, complex ducting and enclosures, screw and fastener testing, and more, can be tested and produced using DuraForm SLS materials.



Where SLS improves on injection molding

Injection molding limits design features whereas additive manufacturing frees designers to achieve more.

When designing a component for injection molding, the strength of the component under load in an end-use environment is a critical consideration. Two easy ways to increase strength of a particular geometry are to increase wall thickness and add ribs. However, while best-practice design guidelines for injection molded components frequently limit designers, 3D printing frees designers by removing several 'cardinal rules' for injection molded component design.

NO CONSTANT WALL THICKNESS REQUIRED FOR SLS

Fundamental to all plastic injection molded design guidelines is the rule that the designer should maintain a constant wall thickness. This rule is intended to address mold filling, packing, shrinkage, residual stress, and warpage issues. In particular, variations in wall thickness create variations in shrinkage, which in turn creates residual stresses, which can cause warpage and premature stress failures.

In contrast, 3D Systems' SLS additive manufacturing eliminates these constraints. Wall thickness can vary as needed with only component geometric boundaries and design stress/strain as limits. Now designers can choose to place material where it's needed, driving increased efficiency in material usage and component strength while reducing both the material cost and build time as compared to a design with constant wall sections. You can now build the part you want, not the part that tooling demands.

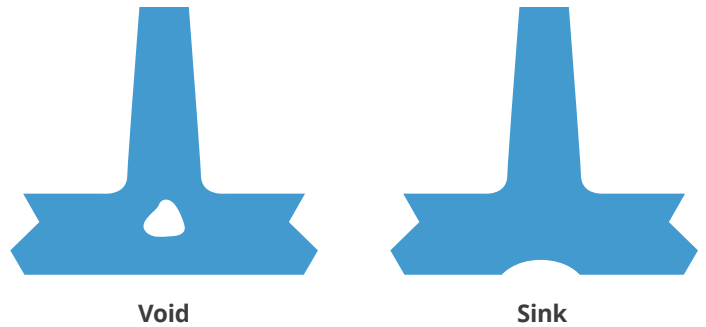
NO CONSTRAINED RIB GEOMETRY WITH SLS

Ribs extending from the surface of a part increase bending stiffness of the part in a more efficient way than simply adding thickness to the surface. Bending stiffness, or resistance against bending deformation, is a function of material elastic modulus, the area moment of inertia (I) of the rib (beam) cross-section, length of rib, and rib boundary conditions. In an injection molding part design those elastic modulus, rib length, and rib boundary conditions must remain constant. This means the only parameter available for the designer to change to achieve greater bending stiffness is the area moment of inertia.

The formula for moment of inertia of a rectangle about its central axis is $I = 1/12 bh^3$ where b is the width of the rectangle and h is the height of the rectangle. This means increasing the height of a rib increases stiffness by the power of 3, versus a linear increase in wall thickness. This is why so many plastic injection molded parts use ribs as an easier way to use a less-costly material with lower elastic modulus and achieve the same or greater bending stiffness.

With design for injection molding, there are 'cardinal rules' designers follow when adding ribs to a component design. Both rules are in place to help the designer avoid problems with the injection molding process (voids due to insufficient mold filling, packing and uniform cooling rates) and component aesthetics (sink marks on the surface opposite the rib).

Fundamentally, the rules are in place to address the physical reality of the injection molding process. When molten polymer compounds are injected into metal molds, it's necessary to assure uniform cooling of the component, or else differential shrinkage will create residual stresses in the component. These residual stresses create challenges with warpage and part performance.



INJECTION MOLDING CARDINAL RULES FOR RIBS

1. Ribs can be no thicker than 50-75% of a primary wall (30% for highly cosmetic parts with materials sensitive to sink marks). Thicker ribs ensure a void at the center of the rib-to-wall intersection and/or a sunken surface (sink mark) on the surface of the component opposite of the rib.
2. Radius the intersection of rib to the primary wall at 0.25 times the primary wall thickness with a minimum radius of 0.010 inch. Neglecting this rule creates a stress concentration at the rib-to-wall intersection and can lead to failure of the component at below-design loads during end-use.
3. Ribs should be kept as short as possible. Rib heights can be no greater than 2.5 times the thickness of the primary wall.
4. Ribs should be tapered on both sides (drafted). Draft angles can range from 0.5 degrees to 2 degrees. This rule is in place solely to enable ease of ejection from the mold. It is worth noting that by requiring the rib to be tapered limits its height, as with greater height the cross section is increasingly thinner.

SLS CARDINAL RULES FOR RIBS

1. Ribs can be as 'thick' as needed. With SLS 3D printing, it's possible to print a hollow rib, achieving greater thickness with no adverse aesthetic issues while maximizing the moment of inertia of the rib. While super-thick and solid ribs are printable, they are not an efficient use of material and lengthen cooling time post-print.
2. Unlike injection molding where a radius comes at an added cost for the tool builder, there is no cost to radius rib-to-wall intersections.
3. Ribs can be as tall as needed, within component geometric boundaries.
4. Ribs do not have to be tapered, and can have a reverse taper (thicker at the rib top vs the rib base).
5. Ribs can have a perpendicular or angled surface on top of the rib, like an I-beam. SLS 3D printing is not constrained by the need to eject the component from a mold. The moment of inertia of an I-beam is much greater than a rectangle.
6. Ribs do not have to be solid from top to bottom, nor along their length. Imagine a truss or a gusset. All of these designs are possible with SLS 3D printing.

DESIGN CHANGES ON THE FLY AT MINIMAL COST

With SLS 3D printing, CAD data replaces tooling. CAD data can be quickly edited to enable immediate design changes and launch production without the wait and cost of tooling. Those changes can include labels, logos, textures, and

geometric changes. This tool-free production approach also enables the creation of custom, products very easily and inexpensively.

Thermoplastics are the key

Thermoplastics have become a leading material in manufacturing, replacing steel in many applications. Thermoplastics are extremely durable, suitable for long-life applications. Now it is possible to reap the benefits of 3D printing with this valuable material, extending the use of thermoplastics with design freedom that bypasses traditional manufacturing limitations.

3D Systems offers a family of engineered thermoplastics specifically for SLS printing, including nylon 11 (PA 11) and nylon 12 (PA 12). 3D Systems' key SLS thermoplastic materials are pure nylon. Engineers can choose specific materials based on their requirements for properties such as:

-  Stiff/rigid
-  Flexible/durable
-  Elastomeric/rubber-like
-  High temperature resistance
-  High elongation
-  High impact strength
-  Flame retardant
-  Food grade
-  Medical grade

PERFECT POWDER PURITY

SLS nylon materials from 3D Systems are formed from pure nylon 11 and nylon 12, without additives and binders. This means that AM nylon parts have exactly the same material properties as nylon parts created using traditional manufacturing methods and do not mimic nylon materials. With SLS nylon materials customers have the same experience that they have experienced and trusted for years, making 3D Systems' SLS platform ideal for production parts.



DuraForm HST Composite: An under-the-hood wonder

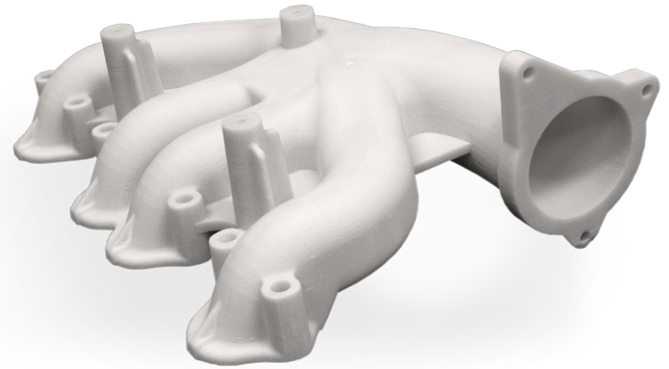
The overarching properties of 3D Systems' SLS materials make nearly all of them great for automotive applications in general. However, when it comes to the rigors of under-the-hood testing, DuraForm® HST Composite tops the list. DuraForm HST is a robust, load-bearing, high heat resistance material, ideal for when you need parts that can withstand an aggressive heat environment and fairly serious pressures or stresses.

Short for High Strength & Temperature, DuraForm HST has a heat deflection temperature of 184 °C and 363 °F at 0.45 MPa. As a fiber-reinforced material, DuraForm HST delivers slightly anisotropic properties just like fiber-filled injection molded materials. When you take its chemical and abrasion resistance into account, there are many under-the-hood applications DuraForm HST can answer.

Examples of parts that are a great fit for DuraForm HST include:

- Oil pans
- Intake manifolds
- Tensioners
- Belt pathways
- Heat shields and covers
- Air filter cases
- Ducting work
- Plenums
- Pneumatic components
- Master cylinder prototypes
- Brackets

DuraForm HST offers a Shore D hardness of 75, an ultimate tensile strength of 48-51 MPa, and an unnotched Izod impact strength of 310 J/m.



DuraForm HST has a heat deflection temperature of **184 °C & 363 °F** at 0.45 MPa

3D Systems On Demand

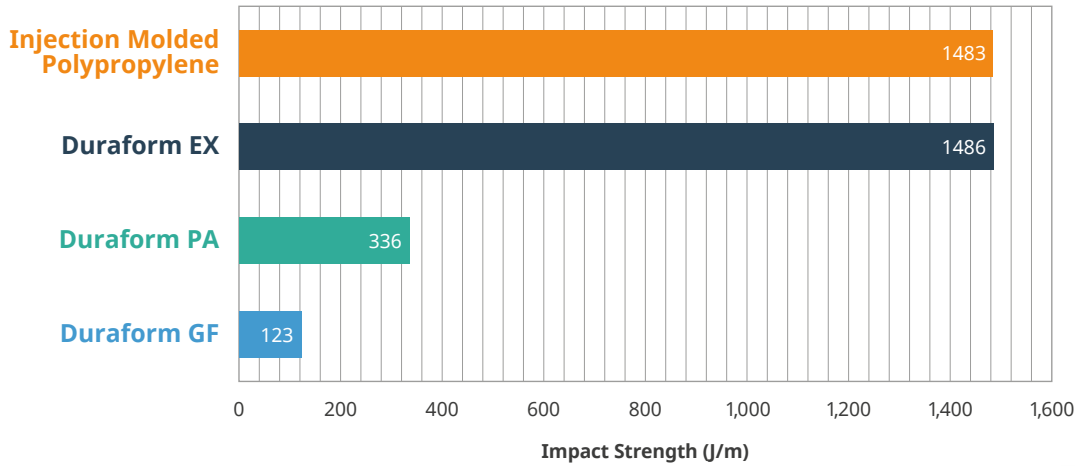
Testing the suitability of DuraForm HST for your application is fast and easy, as a core offering of 3D Systems On Demand services. Whether you need fast turn 3D printed parts, advanced prototyping with assembly and finishing services or low volume manufacturing, 3D Systems' On Demand experts can help advance your project, timeline, and goals. For more information on our complete range of lifecycle support services, contact our On Demand experts.

[Find out more about On Demand](#)



DuraForm® EX: A high performance SLS powerhouse

3D Systems' [DuraForm EX material](#) offers outstanding toughness and excellent impact resistance with repeatable mechanical properties. In testing, DuraForm EX delivers an impact strength that is comparable to that seen with injection-molded polypropylene using unnotched Izod testing.



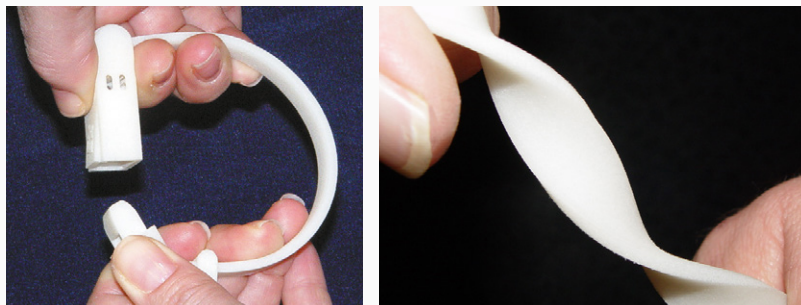
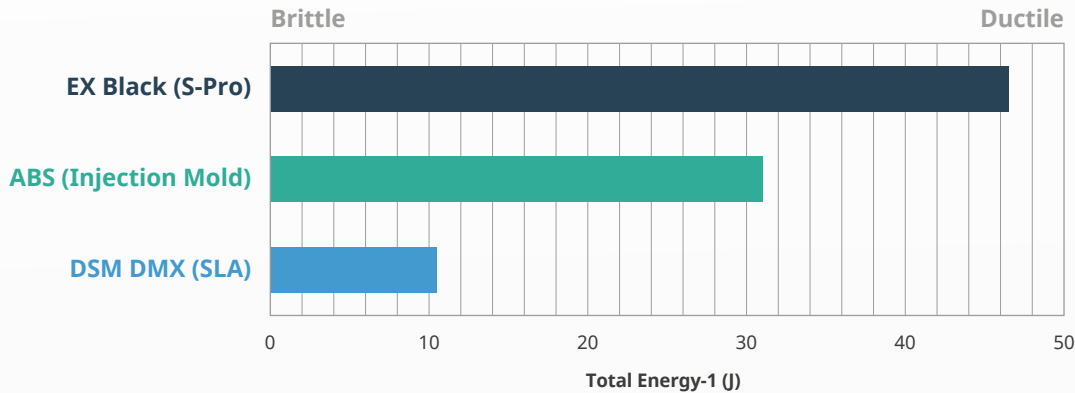
This produces SLS parts that can be used as 'real-world' production parts and also enables functional testing of prototypes. DuraForm EX is ideal for thin-walled ductwork for motorsports, aerospace, and UAVs, automotive bumpers, dashboards, housings and enclosures, impellers, connectors, sporting goods, snap-fit designs, living hinge prototypes, and more. It's also ideal for components that would normally be 'thick-walled' but are now optimized for the SLS additive manufacturing process.

IMPACT STRENGTH

DuraForm EX has superior impact strength in drop dart testing compared to injection molded ABS plastics, with more than 45 J/m on impact.

ELONGATION

DuraForm EX has excellent elongation at break (47%) and flexural strength (46 MPa/PSI) that enables it to be bent many times without tearing.

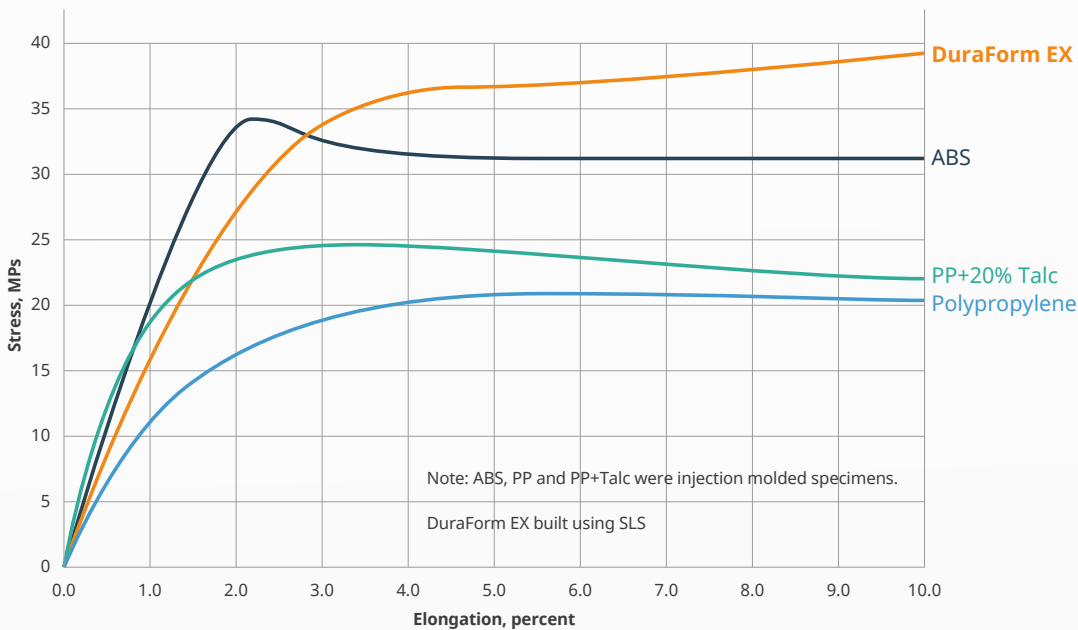


When comparing DuraForm EX to three different injection molded plastics, DuraForm has mechanical and thermal properties that are comparable to or exceed injection molded plastics.

| | | Selective Laser Sintering | Injection Molding | | |
|------------------------------|-------------|---------------------------|-------------------------|-------------------------------|----------|
| Mechanical Properties @ 23°C | | DuraForm® EX | Copolymer Polypropylene | 20% Talc-Filled Polypropylene | ABS |
| MEASUREMENT | ASTM METHOD | METRIC | METRIC | METRIC | METRIC |
| Tensile Strength, Ultimate | D638 | 48 MPa | 21 MPa | 24 MPa | 33 MPa |
| Tensile Modulus | D638 | 1517 MPa | 1241 MPa | 2551 MPa | 1930 MPa |
| Elongation at Break | D638 | 47% | 99% | 39% | 28% |
| Flexural Strength, Ultimate | D790 | 46 MPa | 31 MPa | 43 MPa | 59 MPa |
| Flexural Modulus | D790 | 1310 MPa | 1172 MPa | 3033 MPa | 2137 MPa |
| Impact Strength | | | | | |
| Notched Izod @ 3mm | D256 | 74 J/m | 139 J/m | 41 J/m | 192 J/m |
| Unnotched Izod @ 3mm | D256 | 1486 J/m | 1483 J/m | 862 J/m | 1793 J/m |
| Gardner Impact @ 3mm | D5420 | 11.8 J | >18.1 J | >18.1 J | >18.1 J |
| Thermal Properties | | | | | |
| HDT @ 0.45 MPa | D648 | 188°C | 94°C | 122°C | 103°C |
| HDT @ 1.82 MPa | D648 | 48°C | 62°C | 66°C | 91°C |

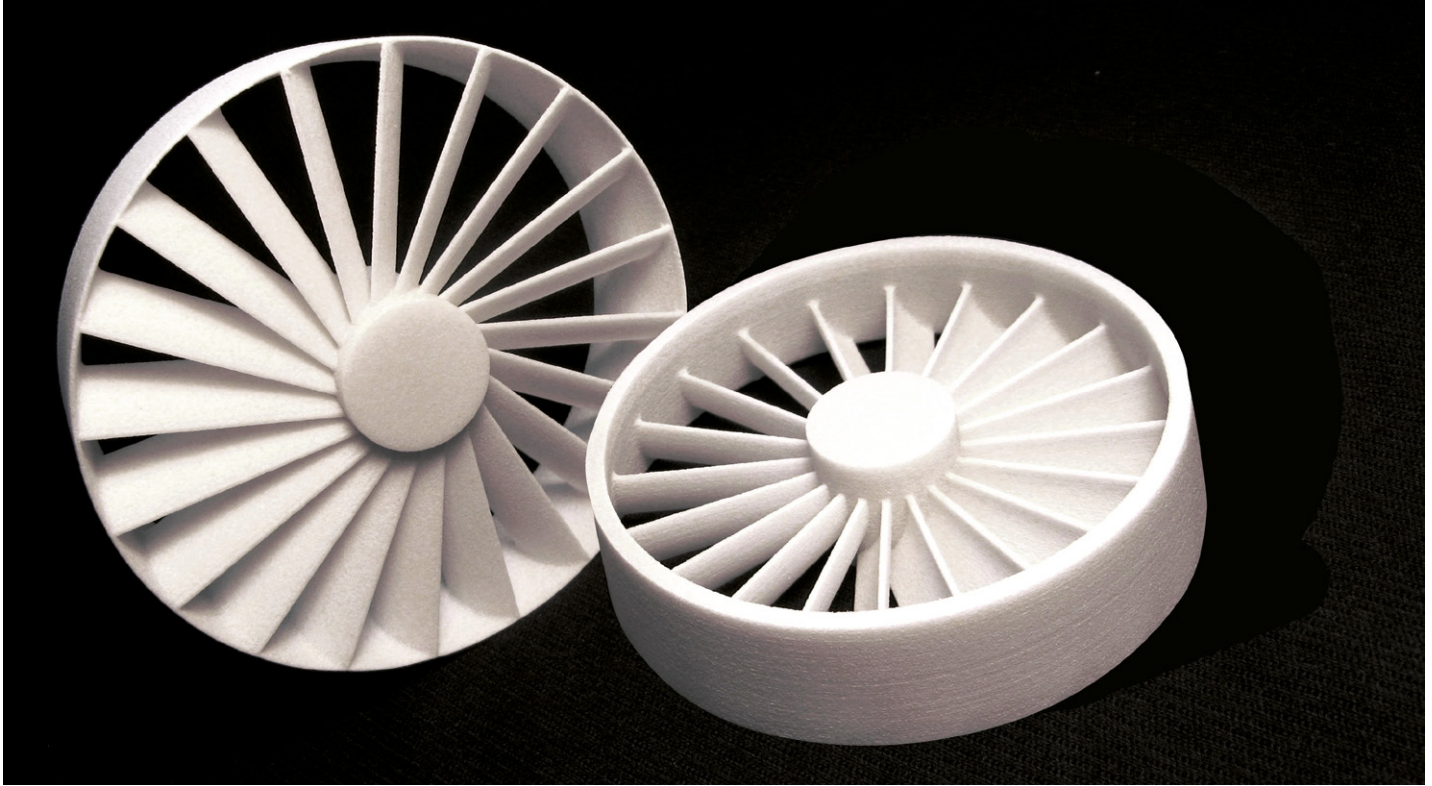
STRESS TESTING

In stress testing, the stress vs. strain curve for DuraForm EX shows it to be a tougher material than the other materials due to the large area under stress.



Since SLS is an additive process that enables complex, consolidated parts, not restricted by the limitations of traditional manufacturing processes, and material properties match or exceed those of injection molded parts, SLS should always be considered for low- to mid-volume production runs of parts as a way to deliver improved part performance and end-use customer satisfaction.

Other SLS Material Properties



EXCELLENT CHEMICAL RESISTANCE

DuraForm PA, a nylon 12 material, possesses excellent chemical resistance. Its strengths are in lower moisture uptake, and environmental stress-cracking resistance when compared to other engineering plastics such as PA6 or PA66, for example.

Testing by materials suppliers of DuraForm PA show that the material has good chemical resistance to over 140 substances. These include alkalis, organic solvents, petroleum products, oils, fats, aromatic and aliphatic hydrocarbons, ketones, and esters. PA12 tends to have good short-term

resistance to diluted organic acids at room temperature. Applications which place components in contact with concentrated acids, oxidizing agents and certain salts (potassium thiocyanate, calcium chloride, and zinc chloride) should be avoided.

Testing has also shown that [DuraForm PA](#) is capable of meeting USP Class VI and the ISO 10993 certifications.

In addition, DuraForm PA is compliant for food contact certification with the FDA's 21CFR, section 177.1500 for nylon resins to be used to produce parts for the processing, handling, and

packaging of non-alcoholic food. It is also compliant with the Plastic Directive of the European Union, No. 10/2011 and regulation (EC) No. 1935/2004 for plastics as appropriate for use in food contact materials.

[Find out more with our SLS eBook](#)

OBSOLETE AUTOMOTIVE PART RECREATED IN SLS

The EcoJet is one of more than 200 cars housed in Jay Leno's Big Dog Garage, and was hand-built by Leno's team. The car features a 650 horsepower Honeywell gas turbine engine, which makes it necessary to push the car out of the garage before starting it because of the jet wash it creates. On one such journey, one of the vents behind the door was inadvertently broken.

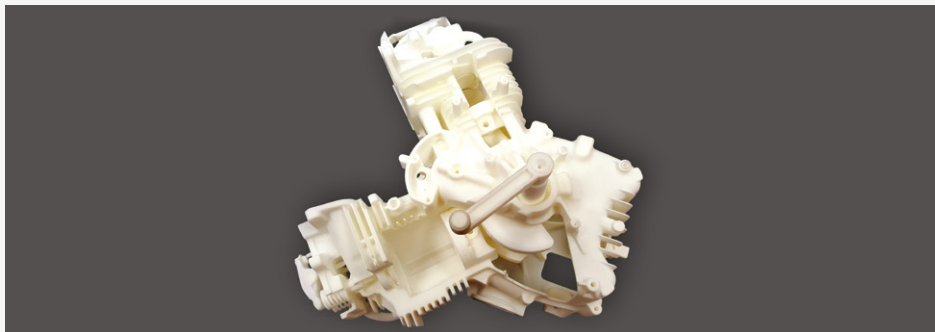
Because the CAD data for the EcoJet had been lost, repairing the car required a complete digital workflow to reverse

engineer the part using 3D scanning and Geomagic Design X. Once the software had been used to recreate the part into a feature-based, editable 3D CAD model, the next step was to 3D print it using selective laser sintering with help from 3D Systems' On Demand team using DuraForm HST Composite. As a fiber-filled nylon with anisotropic mechanical properties, DuraForm HST is ideal for functional prototypes and end-use parts that require high stiffness and elevated thermal resistance. "This is amazing, how we just take 3D scans

and come back with end-use parts that fit perfectly," said Jay Leno. "We could never have done this without 3D Systems."



How SLS and SLS materials are changing the world around us



DEVELOPING & QUALIFYING ENGINES

SLS printing has transformed Briggs & Stratton's prototyping capabilities, introducing new levels of throughput, durability, and accuracy to unlock unprecedented productivity in product development. Briggs & Stratton has also realized significant cost savings since bringing SLS in-house. Briggs & Stratton's SLS prototyping applications run the gamut from blower housings and fuel injector systems, to cyclonic air cleaning systems, mufflers and intake manifolds, just to name a few. In addition to proof-of-concept prototyping for nearly all parts, Briggs & Stratton designers include certain SLS parts on engine fit-ups for early insights into design performance, assembly, and interferences.

Michael Dorna, manager of Briggs & Stratton's Rapid Prototyping Center, recalls receiving a part request for an SLS printed and epoxy-sealed intake manifold: "The next thing I knew I had an order for six more," he says. "I found out these SLS parts are being used to qualify the design, which means they're being run on an air-cooled engine for 2000 hours at wide open throttle. That's a brutal environment, and these parts are holding up."

Across the board, Briggs & Stratton designers praise the speed of SLS because fast access to parts enables them to efficiently move their projects forward with confidence.



DELIVERING NEW BUSINESS MODELS

The smallest design improvements can sometimes yield large impact on product efficiency. Metro Aerospace designed a novel way to reduce drag on aircraft, with a series of microvanes that attach to the aft cargo door of specific aircraft models. Each aircraft requires 20 printed microvanes, each about 10 inches long and unique to the specific location they are installed. A set of microvanes reduces fuel consumption by approximately 25 to 30 gallons an hour while also providing significant reduction in engine wear. They are made on a 3D Systems SLS printer using DuraForm GF, a glass-filled nylon. Because the microvanes are 3D printed, Metro Aerospace builds to order, bypassing the time and expense of injection molding and the cost of keeping inventory. The microvanes deliver ROI within 12-16 months of installation.

How SLS and SLS materials are changing the world around us

PROTOTYPING ASSEMBLY PROCESSES

SLS materials are ideal for prototyping assembly processes including self-tapping screw insertion and torque screws without the material cracking or splitting. This can enable early simulation of the production and assembly process long before the design is complete, and at a point where changes become increasingly more expensive.

POST-PROCESSING CHOICES

Material choice is a key decision in terms of matching application requirements for high temperature resistance or impact strength, but final aesthetics and post-processing needs can also play a role. Since 3D Systems SLS uses nylon as the basis for most of its materials, it is very straightforward to finish with primers, paints, and coatings for a perfect finish.

LOW COST JIGS & FIXTURES

An aerospace company realized that accurate assembly of aircraft panels to the airframe was challenging its production line staff, and yet, making a jig using traditional methods was proving difficult. Using 3D Systems' thermoplastic SLS materials the jig could be made rapidly, directly from the CAD data, to enable almost immediate assembly to begin, enabling the production line to become more efficient.

FASTER MOLD MANUFACTURING

A manufacturer of specialized environmental monitoring equipment followed a traditional method for creating molds for vulcanized rubber shells. Each new mold took months to develop. Working with 3D Systems consulting engineers, the company created a redesign of the mold assembly into a single simplified component. The digital model was then shelled to save material when printed. Working with 3D Systems' materials scientists, they found DuraForm PA to be the perfect match for the new manufacturing method. The new mold was subjected to oven testing of 163°C @ 1.5~2.0 Atmospheres for approximately three hours in the oven, and proved to be the equal of the traditional mold material. The process reduced the mold manufacturing process by six weeks.



Delivering competitive advantage in SLS

A new class of SLS quality: eliminating 'orange peel' effect in SLS.

An anomaly that has typically occurred in SLS 3D printing since it was invented is what's known as 'orange peel', which refers to a common surface finish texture resembling an orange. This orange peel effect occurs for a number of reasons, including material blending using recycled powder that has been through too many heat cycles, resulting in small bumps and imperfections. To minimize orange peel effect, operators may have to conduct additional post-processing steps, perform additional testing protocols, or continually add fresh material.

With the release of the ProX[®] SLS 6100 with its Material Quality Control (MQC) systems, 3D Systems has eliminated any orange peel effect on parts. This is due to increased material and build quality assurance tools including:

- Material Quality Control (MQC) system that feeds used material through a sieve and blends it with fresh powder to an ideal ratio – all automated and on-demand to eliminate any manual processes such as hand loading and blending that may cause uneven layers and an improper mix of powder. The MQC automatically blends, recycles and delivers the material in the ProX SLS 6100 system. These automated actions by the MQC eliminate the inefficiencies that result from the manual material handling used by competitive printers, creating a surface finish that is free of orange peel.
- Patented dual-direction Added Powder Layer (APL) spreads the powder in even layers throughout the build, which is a key factor in eliminating orange peel.
- Optimized powder efficiency with the best recycle rate in the industry which keeps "fresh" powder requirements lower than other printing systems.

The ProX SLS 6100 brings advanced SLS to the market delivering exceptional mechanical properties for materials, a portfolio of production-ready nylons and composites, and 3D Sprint[®], an advanced print-management software for high-performance nesting and slicing.

Features of the ProX SLS 6100 include:

- Continuous operating temperature capability up to 225 °C
- Six channel heater array with independent PID output ratio control
- Minimal standard deviation (LET 15%) on heaters
- Thermal stability with a temperature delta across the build area of + / - 2.9 °C compared to 8 to 10 °C delta on most other printers in its class

- Excellent mechanical properties in density, tensile strength, elongation, modulus and EAB
- High performance part nesting with a 60% higher density capability and 20% larger build volume capacity over similar printers
- Digital scanning code that is developed by 3D Systems scans at 12 meters which is 2x faster than most competitors
- Remote cooling station

[Find out more about the ProX SLS 6100 3D printer for your prototyping and production needs](#)



Macro view of SLS orange peel effect



Macro view of ProX SLS 6100

ACCESS TO UNPRECEDENTED EXPERTISE

3D Systems' regional Customer Innovation Centers provide potential and existing customers the opportunity to test and perfect their additive manufacturing applications in close collaboration with 3D Systems' application engineers. On Demand services for part production are also available across 3D Systems' portfolio of additive manufacturing technologies, enabling anytime production support for one-off projects or low-volume orders.

3D Systems' worldwide teams of application and sales engineers deliver the knowledge and expertise to help customers achieve their production goals using additive solutions. With deep experience of the company's integrated engineering software solutions, additive platforms, and extensive materials, 3D Systems can guide and explain the right decisions to achieving success.

What's Next? Interested in Learning More About Thermoplastic Manufacturing?

Talk to an expert about which materials
and printers would work for you

Get in Touch

3D Systems Corporation
333 Three D Systems Circle
Rock Hill, SC 29730
www.3dsystems.com

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