White Paper

The New World of Thermoplastic Manufacturing

3D SYSTEMS
Additive Manufacturing Solutions

Rewrite 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 mass custom manufacturing as well as functional prototyping. The right additive technologies, materials and finishes are transforming manufacturing.

Digital-direct thermoplastic manufacturing offers exceptional quality while opening the door to novel 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 you measure your finished parts on the three dimensions: 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. Materials specialists, designers, and manufacturing engineers can 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 to know when to use thermoplastic additive manufacturing instead of conventional injection molding.

How Selective Laser Sintering works

Selective Laser Sintering is an additive process that uses a high-powered $C0_2$ laser to fuse small particles of powdered nylon to form three-dimensional parts. The model 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 effects.

Why choose SLS?

DuraForm® SLS materials from 3D Systems are delivered in many forms, including pure Nylon 11 and Nylon 12, both optimized and tolearance-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 certifications for aerospace, and are 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.

Bottom line: when you compare material properties, you'll find DuraForm SLS materials compare very well with common injection molding materials.

These 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 prohibitively costly and slow. Functional prototypes such as crash testing for helmets and baby 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 and SLS additive manufacturing frees designers to achieve more.

When designing a component for injection molding, 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 is to increase wall thickness and add ribs. However, while best-practice design guidelines for injection molded components limit designers, 3D printing frees designers by completely removing several of those 'cardinal rules' for injection molded component design.

CONSTANT WALL THICKNESS, NOT SO FOR SLS

Fundamental and common 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 create residual stresses, which can cause warpage and premature stress failures.

In contrast, 3D Systems SLS additive manufacturing eliminates those 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.

CONSTRAINED RIB GEOMETRY, NOT SO FOR 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 = width of rectangle and h = height of rectangle, so increasing the height of a rib increases stiffness by the power of 3 vs 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, 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. From an injection molding process perspective, ribs should be kept as short as possible and be drafted, or tapered on both sides. 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 no longer have to be tapered, and in fact 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

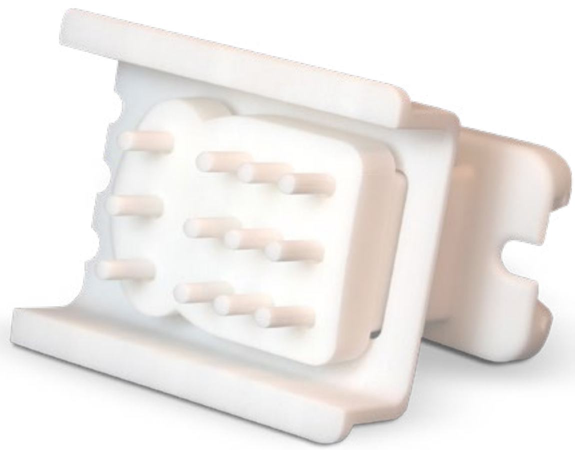
With SLS 3D printing, CAD data replaces tooling. CAD data can be quickly edited to enable immediate design changes and ensuing production without the wait and cost of tooling. Those changes can include labels, logos, textures and geometric changes. This tool-free production approach also enables the creation of custom products very easily and inexpensively.

Thermoplastics are the key – and we've got a lot of them!

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 from Nylon 11 (PA 11), 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
- Food grade
- Medical grade
- Flame retardant

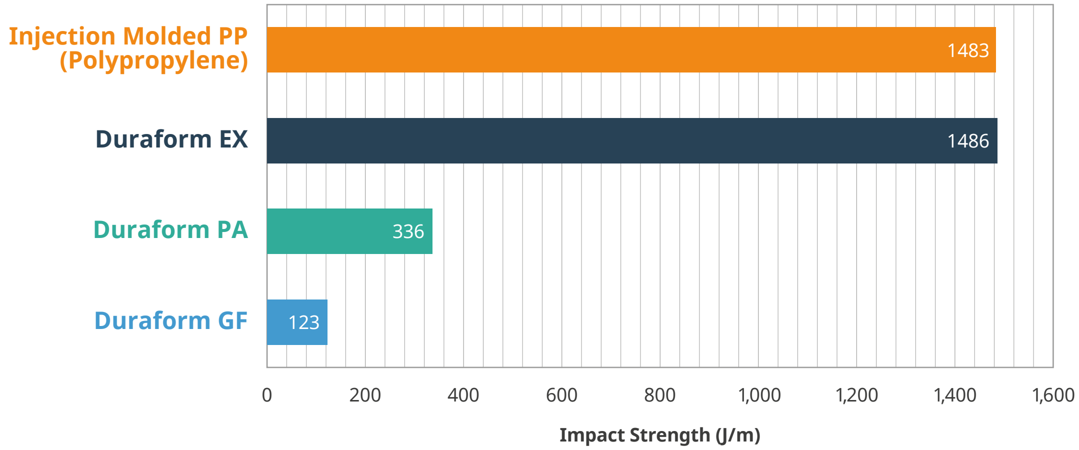


PERFECT POWDER PURITY

SLS Nylon materials from 3D Systems are formed from pure nylon11 and nylon12, without additives and binders. This means that additive 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 learned and trusted for years, making 3D Systems' SLS platform ideal for production parts.

DuraForm EX: a material developed ahead of its time

The DuraForm EX material offers outstanding toughness, 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.



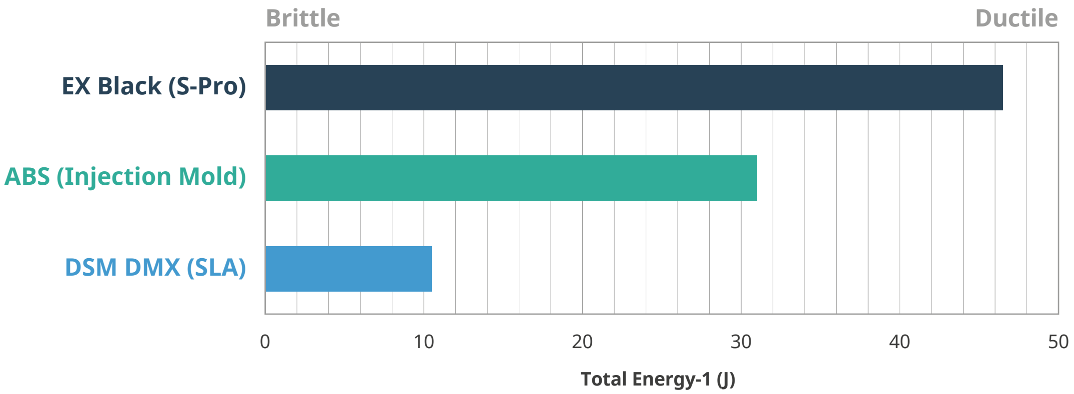
This produces SLS parts that can be used as 'real-world' production parts and also enables functional testing of prototypes. DuraForm EX is ideal for thin-walled ductwork for aerospace, motorsports and UAVs, housings and enclosures, impellers, connectors, sporting goods, automotive bumpers, dashboards, 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.

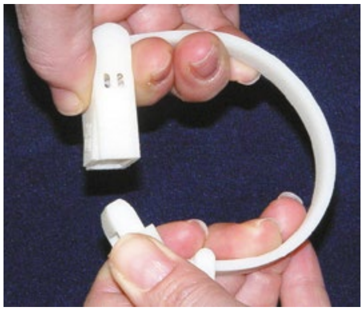
IMPACT STRENGTH

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





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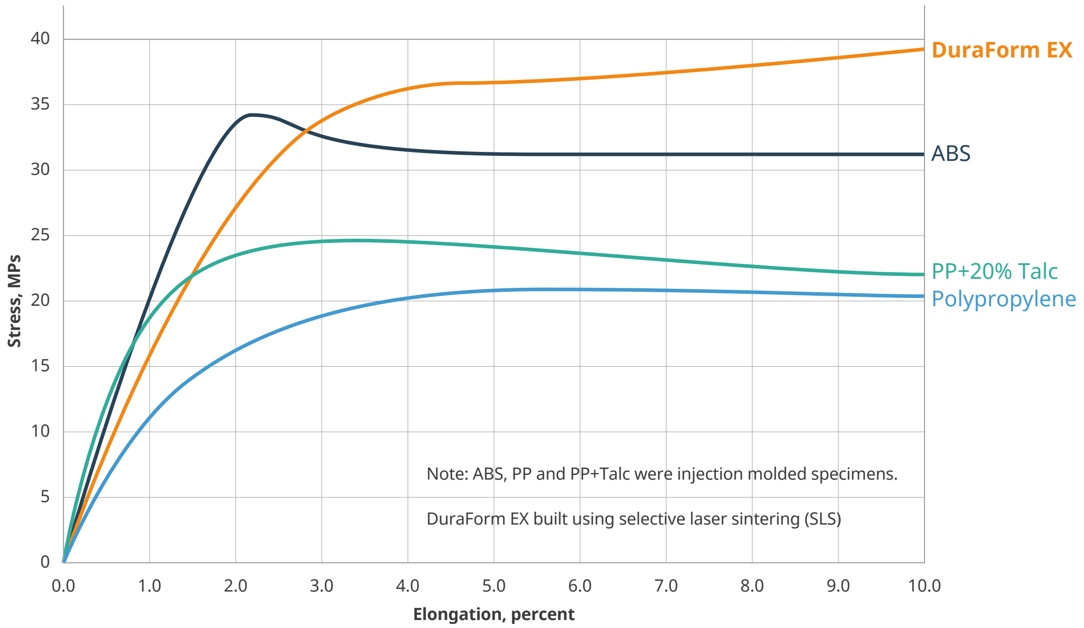
When comparing DuraForm EX to three different injection molded plastics, DuraForm has mechanical and thermal properties that are comparable or exceed injection molded plastics.

		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

NEW TESTING APPROACHES THROUGH INCREASED HEAT DEFLECTION TEMPERATURE

Certain SLS materials from 3D Systems perform very well in high heat environments, enabling functional testing of prototypes in under-the-hood scenarios, housings for consumer products and other elevated heat conditions. DuraForm HST Composite is a mineral fiber-filled nylon that delivers a heat deflection temperature (HDT) of 179oC at 1.82 MPa. With a Shore D hardness of 73, an ultimate tensile strength of 48-51 MPa, and an unnotched Izod impact strength of 310 J/m; parts made in this material can be both load-bearing and have high heat resistance.

SUITABLE FOR FOOD CONTACT AND MEDICAL APPLICATIONS

Testing has shown that the SLS DuraForm PA material 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.

Idaho Steel has been building food processing plants since 1918. In recent years it has expanded to build one-off manufacturing equipment for other industries including aerospace, automotive, medical, consumer, and industrial machining. Key production parts — always custom designed — are now often built using a 3D Systems SLS 3D printer. One of its first applications for SLS was to build forming inserts and pistons for a potato processing machine. The traditional method was to assemble inserts from five separate machined plastic parts held by 25 or more fasteners. The combination of multiple CNC sessions and manual assembly meant 250 hours to complete a set of 16 forming inserts and pistons. Idaho Steel now makes the same number of parts in 90 hours of mostly unattended continuous runtime on the SLS printer. Manual labor in assembly is reduced to about four hours for final assembly. The company says the food-safe DuraForm Pro X PA material is more durable in operation than the traditional solution, and a better sanitation choice as fasteners are notorious for harboring potential contamination.

EXCELLENT CHEMICAL RESISTANCE

DuraForm PA, a nylon 12 material, possess 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.

Find out more with our SLS eBook

INVENTORY REDUCTION OF IN-CABIN AIRCRAFT PARTS

A major Middle East airline wanted to address the issue of reducing time of Aircraft On Ground (AOG) while streamlining the massive parts inventory needed to keep the fleet in the air. Working with 3D Systems' advanced application engineers, the airline developed a streamlined 3D scan, design and print system using the 3D Systems' latest DuraForm FR1200 SLS material, which is FAR 25.853 compliant, flame retardant nylon material that is 10% lighter than the average aviation plastic. The end-to-end process put in place is enabling on-demand production of lighter in-cabin parts for immediate installation on the plane.

How SLS and SLS Materials are changing the world around us

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 specific existing airplane models, and in the process found a profitable new business model. Metro's engineers designed a series of microvanes that attach to the aft cargo door of specific aircraft models. Each retrofitted or new aircraft requires 20 printed microvanes, each about 10 inches long. Each microvane in the set is unique, and they must be applied in specific locations. Metro says the set reduces fuel consumption by approximately 25 to 30 gallons an hour while also providing significant reduction in engine wear.

The microvanes are created on a 3D Systems SLS printer using DuraForm GF, a glass-filled nylon specifically engineered for SLS. The impacted aircraft are used by both civilian and military. The attachments are cutting costs, extending mission time, and providing additional payload capacity. Because the microvanes are 3D printed, the small minority-owned Metro Aerospace builds to order, bypassing the time and expense of injection molding and the cost of keeping inventory on such a detailed and varied set of parts. The microvanes are installed using a custom 3D printed fixture, and they deliver ROI within 12-16 months of installation.

CUSTOMIZED FOOTWEAR

High-tech apparel startup Wiivv Wearables is now selling thousands of customized athletic shoe insoles designed with an app that turns foot photographs into data points. Wiivv then uses proprietary and commercial image processing to convert the data for 3D printing on a 3D Systems SLS printer. Wiivv was so successful with custom insoles it launched a line of custom-fitted sandals with individualized arch support.

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

The choice of material is a key engineering decision to match to requirements for high temperature resistance or impact strength, but also you can factor in post-processing needs and requirements. 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 a headache for the production line staff, and yet, making a jig using traditional methods was a massive challenge. Using 3D Systems' Thermoplastic SLS materials the jig could be made rapidly, direct from the CAD data, to enable almost immediate assembly to begin and for 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 325°F @ 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'. Orange peel occurs for a number of reasons, including material blending using recycled powder that has been through too many heat cycles, resulting in a surface finish defect that resembles the texture of an orange peel with 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 toan 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 Selective Laser Sintering 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

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.

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

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