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The purpose of this white paper is to provide a comprehensive overview of the SLS printing process, its applications and the elements needed to successfully implement it in the wider production cycle. We hope that this paper provides a useful reference and inspires new avenues of innovation, whether you are exploring SLS for the first time, or are already making active use of it in your projects.

RP Platform
What is Selective Laser Sintering?

SLS printing is a powder-based technology. While the earliest 3D printers deposited material layer by layer, using a printer head, SLS works by firing a precisely controlled laser into a powder bed. Once the powder has been preheated by the printing bed, the laser heats it close to its melting point, causing it to fuse together at a molecular level. The laser traces the outline of the model on the powder bed in this way to create a solid layer. Once this is complete, the printing bed drops (usually by less than a millimetre), and a roller adds a new layer
of powder. The laser then traces the next layer of the part in the same way, until a complete print is achieved. The part is then left to cool, after which it can be removed from the printing bed.

Why SLS?

SLS offers a number of key advantages over other 3D printing methods:

- SLS prints do not require support structures during printing, as the powder bed provides each layer with the support it needs. This means there’s no need to factor the removal of supports into the post-processing stage — a considerable time-saver, particularly when multiple parts are being printed at once.

- While SLS parts do not typically require a significant amount of post-processing, there are a wide variety of finishing and colouring techniques available, both to tailor parts’ mechanical qualities, and achieve a wide range of attractive looks. For example, SLS parts are naturally porous, but if this is not desirable, a finish can be applied to seal them.

- A high level of complexity and detail is achievable, including interior components that would not be possible with other methods.

- SLS is eminently scalable. Thanks to minimum material wastage and the increasing speed of printing technology, it is suitable for both prototyping and production applications. Furthermore, the material is often reusable, as any remaining powder can be sieved to remove any impurities after printing, then used in future print runs, helping reduce material costs.

These advantages, combined with increasing sophistication in both materials and printing technology have led to SLS becoming one of the most popular additive manufacturing methods since the first industrial printers became available in the early 1990s. In 2016, around 22% of 3D printing projects used SLS methods, placing it second only to Fused Deposition modeling (FDM), but ahead of Stereolithography (SLA), the original 3D printing method.

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When a powder is brought past its boiling point during printing, the process is referred to as Selective Laser Melting (SLM). The key advantage here is that you will always end up with a single solid part, free of any voids. As the powder actually melts together rather than fusing, the end result is incredibly strong and durable. However, the process can only be applied to prints using a single material, due to the differences in melting point between different materials. This means that printing with any sort of composite material is impossible with SLM techniques.
While the concept of SLS printing was originally conceived in the early 1980s, it wasn’t until 1992 that the first SLS industrial printer was unveiled – DTM’s Sinterstation 2000 (later merged with 3D Systems). This was followed by EOS’s EOSINT P350 in 1994. Since then, a wide (and growing) range of machines have entered the market, allowing for faster and larger-scale printing in an industrial context. The following chart offers a breakdown of the most widely used industrial SLS printers that are available at the time of writing:
<table>
<thead>
<tr>
<th>Name</th>
<th>Maker</th>
<th>Max building speed*</th>
<th>Min/max layer thickness (mm)*</th>
<th>Build capacity (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>ProX SLS 500</td>
<td>3D Systems</td>
<td>2 L/hr</td>
<td>0.08 - 0.15</td>
<td>381 x 330 x 460</td>
</tr>
<tr>
<td>sPro 60 SD</td>
<td>3D Systems</td>
<td>0.9 L/hr</td>
<td>0.08 - 0.15</td>
<td>381 x 330 x 460</td>
</tr>
<tr>
<td>sPro 60 HD Base</td>
<td>3D Systems</td>
<td>60 cu in/hr</td>
<td>0.08 - 0.15</td>
<td>381 x 330 x 460</td>
</tr>
<tr>
<td>sPro 60 HD-HS</td>
<td>3D Systems</td>
<td>110 cu in/hr</td>
<td>0.08 - 0.15</td>
<td>381 x 330 x 460</td>
</tr>
<tr>
<td>sPro 140 Base</td>
<td>3D Systems</td>
<td>185 cu in/hr</td>
<td>0.08 - 0.15</td>
<td>550 x 550 x 460</td>
</tr>
<tr>
<td>sPro 140 HS</td>
<td>3D Systems</td>
<td>300 cu in/hr</td>
<td>0.08 - 0.15</td>
<td>550 x 550 x 460</td>
</tr>
<tr>
<td>sPro 230 Base</td>
<td>3D Systems</td>
<td>185 cu in/hr</td>
<td>0.08 - 0.15</td>
<td>550 x 550 x 750</td>
</tr>
<tr>
<td>sPro 230 HS</td>
<td>3D Systems</td>
<td>300 cu in/hr</td>
<td>0.08 - 0.15</td>
<td>550 x 550 x 750</td>
</tr>
<tr>
<td>EOSINT P390</td>
<td>EOS</td>
<td>35 mm per hour</td>
<td>0.1 - 0.15</td>
<td>340 x 340 x 620</td>
</tr>
<tr>
<td>EOSINT P395</td>
<td>EOS</td>
<td>31 mm per hour</td>
<td>0.1 - 0.12</td>
<td>340 x 340 x 620</td>
</tr>
<tr>
<td>EOS P396</td>
<td>EOS</td>
<td>48 mm per hour</td>
<td>0.1 - 0.12</td>
<td>340 x 340 x 600</td>
</tr>
<tr>
<td>EOSINT P730</td>
<td>EOS</td>
<td>35 mm per hour</td>
<td>0.12 - 0.12</td>
<td>700 x 380 x 580</td>
</tr>
<tr>
<td>EOSINT P760</td>
<td>EOS</td>
<td>32 mm per hour</td>
<td>0.1 - 0.12</td>
<td>700 x 380 x 580</td>
</tr>
<tr>
<td>EOSINT P770</td>
<td>EOS</td>
<td>32 mm per hour</td>
<td>0.06 - 0.18</td>
<td>700 x 380 x 580</td>
</tr>
<tr>
<td>EOSINT P800</td>
<td>EOS</td>
<td>7 mm per hour</td>
<td>0.12 - 0.12</td>
<td>700 x 380 x 580</td>
</tr>
<tr>
<td>FORMIGA P100</td>
<td>EOS</td>
<td>24 mm per hour</td>
<td>0.1 - 0.1</td>
<td>200 x 250 x 330</td>
</tr>
<tr>
<td>FORMIGA P110</td>
<td>EOS</td>
<td>20 mm per hour</td>
<td>0.06 - 0.12</td>
<td>200 x 250 x 330</td>
</tr>
</tbody>
</table>

*Build speed and min/max layer thickness may vary depending on the choice of material.
SLS Materials

The powder used in SLS printing is usually produced by ball milling, where a cylindrical mill grinds the material down to the required consistency. Most powders used for SLS use a mix of materials to get the desired result, although single-material powders are used for certain applications. The first SLS printers used plastic and nylon-based powders, but a wide range of materials are now readily available.

<table>
<thead>
<tr>
<th>PA11</th>
<th>PA12</th>
</tr>
</thead>
<tbody>
<tr>
<td>Low environmental impact</td>
<td>Excellent strength and stiffness</td>
</tr>
<tr>
<td>Good resistance to light, UV and weather</td>
<td>Resistant to chemicals</td>
</tr>
<tr>
<td>Good elasticity and impact resistance</td>
<td>Consistent long-term behaviour</td>
</tr>
</tbody>
</table>
The most popular material used in SLS remains polyamide — a versatile nylon-like material that can be used in a wide range of applications. SLS materials are typically based on one of two core polyamide types: PA11 and PA12. However, now there are also materials available that blend these polyamides with other materials (such as carbon, graphite, glass or aluminium) to create specific mechanical properties. Research is currently underway into using sand and sucrose-based materials for SLS printing, although this is not yet commercially available.

For certain materials, related but different processes are required to successfully print with them. In particular, a similar process to SLS can now be used to create metal 3D printed objects. This is referred to as Direct Metal Laser Sintering (DMLS) and lies outside the scope of this white paper.

Materials Summary

The following table offers an introduction to the most widely-used materials for SLS printing:

<table>
<thead>
<tr>
<th>Material</th>
<th>Maker</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>DuraForm ProX PA</td>
<td>3D Systems</td>
<td>A strong, durable thermoplastic. Only works with the ProX SLS 500 printer.</td>
</tr>
<tr>
<td>DuraForm ProX GF</td>
<td>3D Systems</td>
<td>A stiff, glass-filled material, with high thermal resistance. Only works with the ProX SLS 500 printer.</td>
</tr>
<tr>
<td>DuraForm ProX HST</td>
<td>3D Systems</td>
<td>A fibre-reinforced composite with strong thermal resistance. Only works with the ProX SLS 500 printer.</td>
</tr>
<tr>
<td>DuraForm PA</td>
<td>3D Systems</td>
<td>A nylon material, ideal for engineering applications, with excellent surface details and consistent mechanical properties.</td>
</tr>
<tr>
<td>DuraForm GF</td>
<td>3D Systems</td>
<td>A glass-filled nylon material, designed for engineering applications. Good stiffness and temperature resistance.</td>
</tr>
<tr>
<td>DuraForm EX</td>
<td>3D Systems</td>
<td>Impact-resistant thermoplastic, with similar qualities to injection moulded parts.</td>
</tr>
<tr>
<td>DuraForm HST</td>
<td>3D Systems</td>
<td>A highly durable thermoplastic with fibreglass reinforcement.</td>
</tr>
<tr>
<td>Material</td>
<td>Maker</td>
<td>Description</td>
</tr>
<tr>
<td>---------------</td>
<td>----------</td>
<td>-----------------------------------------------------------------------------</td>
</tr>
<tr>
<td>DuraForm TPU</td>
<td>3D Systems</td>
<td>A flexible elastomer with excellent resistance to abrasion.</td>
</tr>
<tr>
<td>DuraForm Flex</td>
<td>3D Systems</td>
<td>Versatile rubber-like material.</td>
</tr>
<tr>
<td>CastForm PS</td>
<td>3D Systems</td>
<td>Specialist material, designed for creating casting patterns.</td>
</tr>
<tr>
<td>PA D80-ST</td>
<td>EOS</td>
<td>Colour-stabilised nylon material with superior mechanical properties and a slightly rough finish.</td>
</tr>
<tr>
<td>PA 850 nat</td>
<td>EOS</td>
<td>Nylon material, optimised for easy processing.</td>
</tr>
<tr>
<td>PA 850 Black</td>
<td>EOS</td>
<td>Same material as PA 850 in black.</td>
</tr>
<tr>
<td>PA 860</td>
<td>EOS</td>
<td>White nylon material. Design for easy processing.</td>
</tr>
<tr>
<td>PA 250</td>
<td>EOS</td>
<td>Unfilled nylon, stabilised against thermal resistance.</td>
</tr>
<tr>
<td>PA 614-GS</td>
<td>EOS</td>
<td>Easy-to-process, recyclable nylon.</td>
</tr>
<tr>
<td>PA 650</td>
<td>EOS</td>
<td>Glass-filled material, with strong stiffness and dimensional stability.</td>
</tr>
<tr>
<td>PA 615-GS</td>
<td>EOS</td>
<td>Similar to PA 614-GS with higher quantity of glass, for a smoother finish.</td>
</tr>
<tr>
<td>PA 616-GS</td>
<td>EOS</td>
<td>Glass-filled nylon material. Delivers a smoother finish that PA 615 GS, but is harder to recycle.</td>
</tr>
<tr>
<td>PA 415-GS</td>
<td>EOS</td>
<td>Glass-filled nylon, optimised for upcycling, with minimal waste material.</td>
</tr>
<tr>
<td>PA 640-GSL</td>
<td>EOS</td>
<td>Light-weight material with carbon fibre. High strength and surface detail. Resistant to high temperatures.</td>
</tr>
<tr>
<td>PA 601-CF</td>
<td>EOS</td>
<td>Strong, lightweight material, reinforced with carbon fibre. Ideal for industrial parts.</td>
</tr>
<tr>
<td>PA 620-MF</td>
<td>EOS</td>
<td>Strong, heavy, mineral-filled material, designed for industrial applications.</td>
</tr>
<tr>
<td>PA 605-A</td>
<td>EOS</td>
<td>Strong aluminium-filled material with excellent surface detail and machinability.</td>
</tr>
<tr>
<td>PA 606-FR</td>
<td>EOS</td>
<td>Fire-retardant nylon material, approved for aerospace applications.</td>
</tr>
<tr>
<td>PA 802-CF</td>
<td>EOS</td>
<td>Carbon-fibre filled nylon, with low density, high stability and excellent tensile modulus.</td>
</tr>
<tr>
<td>PA 840-GSL</td>
<td>EOS</td>
<td>Lightweight material with fibre reinforcement. Excellent surface detail and mechanical qualities.</td>
</tr>
<tr>
<td>Material</td>
<td>Maker</td>
<td>Description</td>
</tr>
<tr>
<td>--------------------------</td>
<td>-------</td>
<td>---------------------------------------------------------------------------------------------------------------------------------------------</td>
</tr>
<tr>
<td>PA 2200</td>
<td>EOS</td>
<td>Versatile multi-purpose material, approved for food contact. Wide selection of finishing options.</td>
</tr>
<tr>
<td>PA 2201</td>
<td>EOS</td>
<td>Balanced material with excellent strength and stiffness. Good chemical resistance and fully biocompatible.</td>
</tr>
<tr>
<td>PA 2202 black</td>
<td>EOS</td>
<td>High level of achievable detail combined with high durability, stability and resistance to abrasion.</td>
</tr>
<tr>
<td>PA 2210 FR</td>
<td>EOS</td>
<td>Flame-retardant and halogen-free, with good mechanical properties and long-term behaviour.</td>
</tr>
<tr>
<td>PrimePart® FR (PA 2241 FR)</td>
<td>EOS</td>
<td>An economic, fire-retardant material, with high tensile strength.</td>
</tr>
<tr>
<td>PA 3200 GF</td>
<td>EOS</td>
<td>High stiffness and wear resistance. Good thermal loadability and excellent level of accuracy and detail.</td>
</tr>
<tr>
<td>FR-106</td>
<td>EOS</td>
<td>Polyamide material, designed for fire, smoke and toxicity resistance.</td>
</tr>
<tr>
<td>Alumide®</td>
<td>EOS</td>
<td>Aluminium-filled nylon, which is easily machined and works with a number of post-processing services. Excellent stiffness and dimensional accuracy.</td>
</tr>
<tr>
<td>CarbonMide®</td>
<td>EOS</td>
<td>Lightweight material with extreme strength and stiffness.</td>
</tr>
<tr>
<td>PrimePart® Plus (PA 2221)</td>
<td>EOS</td>
<td>Versatile, economic material, with balanced properties and good mechanical strength.</td>
</tr>
<tr>
<td>PrimePart® ST (PEBA 2301)</td>
<td>EOS</td>
<td>High elasticity and strength combined with good chemical resistance. A wide range of finishing options can be used.</td>
</tr>
<tr>
<td>EOS PEEK HP3</td>
<td>EOS</td>
<td>Excellent performance at high temperatures. Sterile, and resistant to fire, smoke and chemicals.</td>
</tr>
<tr>
<td>PrimeCast® 101</td>
<td>EOS</td>
<td>Simulates the qualities of polystyrene, with high surface quality and excellent level of achievable detail. Good level of wear resistance.</td>
</tr>
<tr>
<td>PS 100</td>
<td>EOS</td>
<td>Polystyrene material designed for printing casting patterns.</td>
</tr>
<tr>
<td>Material</td>
<td>Maker</td>
<td>Description</td>
</tr>
<tr>
<td>--------------</td>
<td>---------</td>
<td>------------------------------------------------------------------------------------------------------------------------------------------------</td>
</tr>
<tr>
<td>PS 200</td>
<td>EOS</td>
<td>Specialist material for printing casting patterns, optimised for Sinterstation platforms.</td>
</tr>
<tr>
<td>Flex TPE</td>
<td>EOS</td>
<td>Recyclable material, with extreme elongation.</td>
</tr>
<tr>
<td>Nylon 12 AF</td>
<td>Stratasys</td>
<td>Aluminium-filled nylon material, with a high-quality surface finish.</td>
</tr>
<tr>
<td>Nylon 12 PA</td>
<td>Stratasys</td>
<td>A versatile, durable thermoplastic.</td>
</tr>
<tr>
<td>Nylon 12 GF</td>
<td>Stratasys</td>
<td>Glass-filled material with an above-average tensile modulus.</td>
</tr>
<tr>
<td>Nylon 12 HST</td>
<td>Stratasys</td>
<td>Mineral-filled plastic with excellent strength and temperature resistance.</td>
</tr>
<tr>
<td>NyTek™ 1200 CF</td>
<td>Stratasys</td>
<td>Carbon-filled material, with high strength and stiffness combined with electrostatically dissipative qualities.</td>
</tr>
<tr>
<td>Nylon 11 D80</td>
<td>Stratasys</td>
<td>Impact-resistant nylon, free of anti-oxidants, similar in properties to moulded ABS.</td>
</tr>
<tr>
<td>Nylon 11 EX</td>
<td>Stratasys</td>
<td>Similar in properties to moulded ABS, but with a superior surface finish.</td>
</tr>
<tr>
<td>NyTek™ 1200 GF</td>
<td>Stratasys</td>
<td>Glass-filled nylon, with strong stiffness and dimensional stability.</td>
</tr>
<tr>
<td>NyTek™ 1200 PA</td>
<td>Stratasys</td>
<td>Durable material with excellent surface detail. Resistance to chemicals and moisture.</td>
</tr>
<tr>
<td>NyTek™ 1200 FR</td>
<td>Stratasys</td>
<td>Fire-retardant material with excellent surface accuracy.</td>
</tr>
<tr>
<td>NyTek™ 1100</td>
<td>Stratasys</td>
<td>High-elongation polyamide material</td>
</tr>
<tr>
<td>NyTek™ 1100B</td>
<td>Stratasys</td>
<td>Black-coloured version of NyTek™ 1100B, with identical properties.</td>
</tr>
</tbody>
</table>

**Minimising material waste**

An ongoing concern for SLS operations is the minimisation of material waste. While leftover powder can indeed be gathered from the printing bed once a part is removed, reusing it in future projects remains problematic. Certain materials are limited in this regard by their quality and purity, and even with the the highest degree of precision during the printing process, particles will fuse together without adhering to the actual part. This affects the powder’s consistency and, in turn, the quality of future prints if the powder is reused.
Newer model printers have attempted to solve this conundrum by incorporating sieving mechanisms to remove any unwanted clumps of powder, or integrated gas flows that remove any byproducts of the printing process, minimising chemical changes to the powder bed. Once this has taken place, the purified leftover powder can be mixed with new powder for future print runs. However, it must be noted that for certain applications where material specifications must be of the most precise standards (medical, for example), mixing materials like this should not take place, as the margin for error will still be too high.

When investing in an SLS printer, consider whether material costs will be an ongoing concern within your operation, i.e. if you are planning on using your printer in a production capacity, or are using a particularly costly material. In such cases, a printer with ‘upcycling’ capabilities may represent a good long-term investment.

Getting the best possible results from your SLS materials

Regardless of which material and which printer you are working with, we would recommend that you always adopt the following guidelines when printing with SLS techniques:

- Allow a minimum of 0.5mm line thickness for fine details
- Always make sure you have incorporated escape holes for leftover powder. They should be at least 2mm in diameter.
- If you are printing multi-part models, allow at least 0.5mm clearance between any interlocking parts.
- A wall thickness of 1mm is a sensible rule of thumb, although you may wish to increase this for larger prints, for the sake of extra strength.
- For any large, flat surfaces, consider incorporating internal ribbing into your design. This will help minimise the risk of warping.
Post-Processing

As with most 3D printing technologies, a degree of post-processing is required once an SLS part leaves the printing bed. However, the beauty of SLS is that this process is (for the most part) relatively straightforward compared to other technologies. As SLS printing does not require support structures of any kind, there is no need to remove these. There are also a wide range of colouring and finishing options available to enhance both aesthetic and mechanical qualities.
Cleaning the Part

Before any post-processing can take place, it’s essential that all left-over powder is removed and the part is thoroughly cleaned of dirt, oil or finger marks. To begin with, check all escape holes in your part to ensure they have not become clogged with powder during the printing process. Once this is done, a gentle wash in alcohol or warm, soapy water will usually be sufficient for cleaning. Bear in mind that SLS prints often have fragile parts that could be damaged by more aggressive cleaning methods — so exercise a light touch.

Achieving the Right Surface Quality

SLS prints have an inherently grainy quality when they leave the printing bed, but this is easily remedied. Light sanding may be sufficient, but if layers are visible, you may wish to apply some filler. Standard fillers can be used for this purpose, but there are several specialist filler materials for 3D-printed parts on the market now. Before making a purchase, be sure to read each filler’s specifications in detail to ensure it will be a good match with your chosen printing material.

Once the filler has been applied, further sanding will be necessary to smooth out the part’s surface. Start with a coarse-grain paper, and work through finer grains, using a light touch throughout. Avoid the use of hand-grinders, as these can leave scratches and damage fragile parts.

WHAT ABOUT HIGH-VOLUME PRODUCTION RUNS?

For larger print runs, finishing by hand will likely prove impractical, but there are other methods of finishing parts’ surfaces that are ideal for such situations.

➤ Bead-blasting. As the name implies, this involves blasting parts with fine beads of an abrasive material. While this must still be done by hand, it typically only takes around 5-10 minutes and results in an attractive matte finish.
**Tumbling/vibro-finishing.** This process involves placing parts in a rotating drum filled with a ceramic abrasive material, which will smooth out the finish over the course of several hours. While this does take longer than bead-blasting, it allows larger quantities of parts to be finished at once, and so can actually prove to be a time-saver, in practice. Do exercise caution, however, as the wrong choice of material can result in the loss of fine detail and sharp edges becoming smoothed out.

**Vapour finishing.** This involves the use of acetone (or similar solvents, such as butanone or tetrahydrofuran) to melt the surface of parts in a controlled manner, leading to a smooth finish.

A select number of dedicated specialists are now offering finishing services of this sort. We would recommend investigating this option if you are planning on using SLS for high-volume prototyping or production, as it will dramatically speed up your post-processing stages and may well deliver results that would not be achievable in-house.

### Adding Colour

While coloured materials for SLS printing are currently in development, these are still very limited in scope and require the use of specialist printers. Painting or dyeing your part therefore remain the best options for giving your part a vivid, full-colour look.

### PAINTING AND SPRAYING

Acrylic paints are the best choice for SLS applications, although acrylics and cellulose are also viable choices. Before any paint can be applied, the part will need to be thoroughly cleaned and primed.

When painting by hand, always be sure to thin your paints with water, and start with a smooth, even base-coat of your part’s main colour. It is always best to apply several thin coats of each colour rather than a single thick one, as this will keep your colours even and avoid any excessively thick areas affecting your part’s dimensions. Certain colours will require more coats
than others, so don’t panic if the result isn’t ideal after the first couple of coats. For example, black will usually only require a couple of thin coats, while yellow or gold will require several additional layers.

Painting by hand offers a tremendous range of opportunities for creating unique finishes for your parts. For example, an ink wash can be used to add depth, while dry-brushing can enhance fine details. However, for high-volume production parts, you are unlikely to have the sort of time these techniques will require available to you. In these cases, spraying or airbrushing your parts is the ideal solution. This allows a smooth consistent finish to be applied to multiple parts at once, although naturally you will only be able to apply a single colour. As a compromise, you might consider spraying your parts’ basecoats, then bringing out certain details by hand. Alternatively, parts could be printed in separate components, sprayed individually in different colours, then glued together (more on that below).

Finally, always allow your paints to dry properly before applying additional layers. Your paints will generally have the recommended drying time indicated on the packaging, although it is advisable to exceed these times when working with SLS prints.

**DYEING**

Dyeing SLS prints involves immersing the whole part in a bath of acid-based dye. This provides consistent finishing for even the most complex geometries, with relatively little effort. This technique also delivers a durable, scratch-resistant result, particularly with more porous materials. Dyeing also has no effect on part geometries, making it a good option for functional parts. However, it will not achieve the same glossy look as painting, so extra finishing may be required.

When you remove your part from the dye bed, make sure any excess dye has been removed. Not only will this help avoid a ‘blotchy’ look, it will also ensure your part’s dimensions are unaffected by the process. In the interests of caution, we would recommend placing the part in boiling water for a few minutes, to ensure all excess dye has been removed from any hidden areas.
Gluing and Welding Parts

Although SLS printers are capable of printing interlocking parts together, as part of a single print run, you might find you wish to print parts separately and fix them together once they have left the printing bed. This will allow you to create parts larger than your printer’s printing area would allow, and also allow you to colour each component individually, if required. Popular choices for gluing printed parts are:

- **Cyanoacrylate/superglue.** Should be avoided when gluing coloured parts, as it will damage the colours. However, it is strong, and resistant to chemicals and temperature changes.
- **Epoxy.** Can be used with any material and doesn't affect parts’ colours, but can be quite time-consuming to mix and apply.
- **Neoprene.** Can work with any material, but takes time to dry and will be visible if not applied carefully.

As an alternative to gluing, SLS parts can be welded together using a ‘slurry’ made by mixing acetone and your chosen powder material. A key advantage of this is that no new materials are added to the part, and so the joints will respond in exactly the same way as the rest of the part. It will also typically result in stronger bonds than gluing. Much like superglue, this alternative is extremely quick and bonds parts in a matter of seconds.

Coating

Once a part has been coloured, you may wish to apply a final coating, either to keep your part looking clean and new for longer, or to enhance its mechanical qualities. This coat can be applied by hand or spray-painted on, but some professionals have explored the use of dip coating for their parts. In this process, parts are immersed in the coating solution for around ten minutes, then removed and allowed to dry in a vacuum. This can be a good option for parts
with complex geometries, but it requires a certain degree of precision when mixing the coating solution in order to ensure the result is of the desired thickness. The large quantities of solution required can also prove expensive, although this does mean multiple parts can potentially be finished at once.

Material used for coating SLS parts include:

- Epoxy.
- Polyurethane.
- Silicone.
- Laquer.
- Acrylic varnish (matte and gloss).

Coats can be used to simply protect parts from scratches or faded colours, but they can also be used for functional parts to make them waterproof, or resistant to chemicals, temperature changes, and friction.

**Metal Plating**

A more sophisticated technique for coating SLS parts involves adding metal plating, either for functional or aesthetic reasons. There are two ways of doing this:

- **Electroplating.** This involves immersing your part in a plating solution of water and metal salts, then passing an electrical current through it, causing metal cations to form a thin coating around the part.

- **Electroless plating.** This process is similar, but doesn’t require any electrical power and utilises chemical reactions to cause the metal to bond to the part.

Both treatments produce excellent results. As a general rule, electroplating is faster, although several treatments may be required for thicker coats. Electroless plating is more time-consuming, but the resulting finish will be more resistant to friction and corrosion. A skilled technician can monitor the treatment to adjust the thickness of the plating.
PRIMING YOUR PART FOR PLATING

You'll need to prime your part before any plating can take place. For electroplating, this involves a thin layer of conductive material that the plating can adhere to. Graphite is widely used for this purpose. For electroless plating, you should begin by oxidising the surface of your part, then applying a catalytic layer that the plating solution can bond with. The material specifications for your plating solution should provide guidance regarding priming and what options will be suitable.

Materials for plating your SLS parts

FOR DISPLAY PARTS

► Brass
► Copper
► Silver
► Gold

FOR FUNCTIONAL PARTS

► Zinc
► Nickel
► Chrome
► Titanium
Software Tools

Most SLS prints begin life as STL files, which still remains the most commonly used file format for 3D printing applications. This means you have a wide range of CAD applications and data preparation tools to choose from when working with SLS.
Popular CAD applications for SLS modelling include:

3-MATIC

3-Matic is Materialise’s in-house 3D modelling solution, and — as is to be expected — can be fully integrated with the rest of its suite of products. It includes a number of specialist tools for working with lightweight models, cleaning up data as you work, and simulating the physical properties of the finished part, depending on the properties of the material that will be utilised.

AUTOCAD

Originally released in 1982, AutoCad is very much the ‘old guard’ of CAD software. Nonetheless, it remains a popular choice among many manufacturers and designers. It’s especially popular amongst architects and engineers, and has the advantage that many professionals are already well-acquainted with its tools and functionality. This can prove a massive boon if you are incorporating 3D printing into your operation for the first time, helping deliver a smoother implementation.

BLENDER

Blender is free, but its sophisticated design tools mean it has found a user-base beyond bedroom hobbyists. Like Z-brush, it’s generally more suited to creative applications than industrial ones, and comes with quite a steep learning curve, but the range of features it offers means it is certainly worthy of consideration. Also, a large online community means that new features and updates are regularly rolled out, and support or advice can be easily accessed when needed.
CATIA

CATIA is another high-end software platform that is well-regarded for its surface modelling capabilities. In addition to its CAD capabilities, it also offers CAM and CAE functionality, making it a highly versatile solution. The software is well-established across a number of industries, particularly automotive and aerospace. While it does involve a steep learning curve, it is a good choice for complex projects where multiple designers will be involved, as it offers specialist tools to enable remote collaboration.

CREO PARAMETRIC

Creo Parametric (formerly called Pro-Engineer) is popular among medium-sized manufacturers for its wide range of specialist modules, allowing it to be used for a range of applications. It originally established its reputation through its parametric modelling capabilities, something that its makers have continued to refine with each successive version.

INVENTOR

Inventor is primarily used for mechanical design, and offers freeform, direct and parametric modelling tools in this regard. Like Rhinoceros 3D, it makes use of NURBS to deliver highly detailed surface modelling, although it lacks other platforms’ more specialist functions, such as cost analysis and material-specific modelling. It also offers effective file conversion and data exchange capabilities, allowing it to work well with other software platforms.

MESHMIXER

Unlike the other platforms we’ve considered, Meshmixer was actually specifically designed for 3D printing applications, and
incorporates a dedicated set of tools for designing printable models and exporting them as STL files. In particular, it incorporates various file-checking tools to ensure there will be no issues when your model is sent to the printer. This integrated approach is definitely a good choice if you are looking to limit the number of stand-alone software tools used in your operations.

RHINOCEROS 3D

Rhino is a popular choice among product designers and engineers, particularly for the high level of detail that it can achieve. However, it’s important to note that it bases its modelling on NURBS — a highly precise mathematical model — rather than polygons or mesh, as other CAD programs do. This means that you may need to get used to a completely new approach when creating your models, although the potential rewards are certainly great.

SIEMENS NX

NX combines CAD, CAE and CAM functions with PLM capabilities, offering a lot of the same capabilities as dedicated simulation software in a single, integrated package. This means it is suitable for engineering analysis and manufacturing applications, not just design ones. It is widely used across the automotive and aerospace sectors as a powerful (albeit expensive) all-in-one solution.

SOLIDWORKS

Solidworks is the favoured tool for designing mechanical objects among many manufacturers. While its range of tools makes it ideal for such sophisticated designs, you will need to get used to working with sketches, which may take time. As it is often regarded as the premier 3D modelling application, it represents a considerable financial investment. However, there are currently three different versions available, which means you can choose the one which suits your needs and your
For creative applications, like sculptures and figurines, ZBrush is the choice of many professionals. It’s ideal for organic shapes and fine details, although it is probably not the best choice for industrial applications due to most of its functionality being tailored towards artistic projects. Nonetheless, if you’re looking to create something a bit different, its popularity among digital sculptors is a testament to its capabilities.

Data Preparation Tools

Once a design has been finalised, it is crucial that the resulting file is properly checked to ensure it will be printable. We would strongly recommend utilising a dedicated data preparation tool for this purpose, as even small, difficult-to-spot errors can render parts unprintable. For simple designs, you can usually automate the entire checking and repair process, so any errors that are detected will be repaired automatically, with no manual steps required on your part. For more complex models, where any changes – even small ones – could potentially affect the physical geometry of the part (architectural models, for example) you should check any errors that are flagged and confirm whether they should be repair automatically in order to ensure the integrity of your model.

The following are well-established data preparation tools among additive manufacturing professionals. Some are stand-alone data preparation tools, while others are software suites that incorporate integrated data preparation elements. If you are planning on utilising a stand-alone tool, make sure that it will be able to communicate with your other software platforms before making the investment.
3D SPRINT

This is 3D Systems’ in-house platform for managing additive manufacturing production workflows, designed specifically for their own range of plastic 3D printers. It incorporates integrated tools for data repair.

MAGICS

Materialise’s well-established Magics suite of software tools includes a number of tools for data preparation. This includes a ‘wizard’ feature, to guide the user through some of the more sophisticated applications, and tools to optimise designs for printing through techniques such as 3D textures and patterns.

POLYGONICA

Polygonica’s mesh processing software incorporates facilities for repairing 3D project files, notably an algorithm for fine control of hole repair.

RHINO3DPRINT

This is a plug-in for the Windows version of Rhinoceros NURBS (bear in mind that it will not run on the Mac version). While it is the ideal solution if you are designing your parts with NURBS, it will not be usable with other CAD applications.

RP PLATFORM

RP Platform incorporates tools for both manual and automated file
repair as part of its facilities for receiving and managing customer requests. As with all aspects of the platform, the file repair tools can be configured to the user’s specifications. Furthermore, they integrate seamlessly with the platform’s tools for order and production management.

Slicing tools

Related to effective data preparation is slicing: the process of converting a 3D model in printable ‘slices’ that can be laid down by a 3D printer and generating the G-code needed to communicate with the machine. Slicing programs divide up models in this way, then calculate how much material must be laid down on your printing bed for each layer. These tools have grown in sophistication over the years and can now utilise sophisticated adaptive algorithms that calculate the optimal layer height for a part in order to minimise layer visibility in the finished product.

<table>
<thead>
<tr>
<th>The Different Types of Slicing Algorithm</th>
</tr>
</thead>
<tbody>
<tr>
<td>➡️ TRIVIAL SLICING. This is the simplest approach, and works by analysing the intersections of every triangle in the mesh. While it is effective, it can be quite slow compared to other methods.</td>
</tr>
<tr>
<td>➡️ SWEEP PLANE SLICING. This approach involves ‘sweeping’ the 3D model from the bottom up with a simulated plane, which triggers an event every time it passes a vertex of Z coordinate, using this to generate information that can be read by the printer.</td>
</tr>
<tr>
<td>➡️ TRIANGLE GROUPING. This creates slices by grouping triangles according to their Z coordinates.</td>
</tr>
<tr>
<td>➡️ INCREMENTAL SLICING. This algorithm makes use of an internal mesh rather than a triangle-based one, for additional speed and precision.</td>
</tr>
</tbody>
</table>
Popular slicing tools among AM professionals include:

**3DPRINTEROS**

This cloud-based platform offers a range of tools suitable for industrial 3D printing, including three different slicing tools. While some features require additional payment to unlock, the slicing functions are all free to use.

**ULTIMAKER CURA**

Ultimaker’s Cura slicing program is used by both beginners and professionals for its dependability and ease of use, although it lacks the advanced features of more sophisticated platforms.

**ICESL**

IceSL is one of the most sophisticated slicing tools on the market, and also provides tools for 3D modelling, allowing you to make direct edits to your mesh as you prepare it for printing. While there is certainly a learning curve involved, its capabilities are hard to match for sophisticated applications.

**KISSLICER**

This is a straightforward ‘all purpose’ slicing tool, with facilities for multi-head printing and combining multiple STL files in a single print run.
AUTODESK NETFABB

Netfabb’s platform provides a range of slicing tools in all versions of its product, along with a wide arsenal of related data preparation tools. It is an excellent choice if you are looking for a truly integrated suite of software tools for working with STL files.

SIMPLIFY3D

This highly sophisticated platform gives you the ability to work with STL, OBJ and 3MF file formats. The range of options available is huge, although there is definitely a learning curve involved in order to make full use of its capabilities.

SLIC3R

Slic3r offers a huge number of sophisticated features, such as the ability to vary infills layer by layer and split models into separate components for printing, as well as variable layer heights. New features are constantly being added in response to user feedback.

SLICECRAFTER

This is IceSL’s Mac-based counterpart. Although it does not feature the full range of features offered by IceSL, the slicing tools are virtually identical.
SLS originally established its reputation as a tool for prototyping. The ability to quickly deliver limited-run or one-off designs for an affordable price proved highly attractive across a number of industries. However, as is the case with 3D printing as a whole, SLS is slowly making a move into the wider production cycle.

However, for SLS technology to become the norm in manufacturing, a number of challenges must first be overcome.
Developing an effective volume packing process

One key challenge that additive manufacturing has faced since its inception is that it does not provide the same economies of scale as traditional, subtractive methods do. In other words, there is no cost-saving to be had by producing one hundred parts rather than one. While this remains the case, it is still essential that an effective volume packing process is in place. This will provide the following benefits:

- Shorter build times for high-volume production runs.
- More effective machine scheduling, with the absolute minimum number of machines left idle at any given time.
- Minimal material wastage, as more powder will be used in each printing run, minimising the volume of material that must be recycled or disposed of.

The good news is that SLS provides a great deal of flexibility when it comes to part orientation. As parts do not require support structures during printing and will not have their overall quality affected by changes in orientation, one of the key challenges of effective volume packing is eliminated. Things becomes more challenging when multiple machines, possibly incorporating different sizes of build area, are included in an operation. Furthermore, SLS printers all possess an upper limit in terms of how many parts can be ‘stacked’ within their printing areas, as after a certain point, it will become impossible for the printer to add enough powder to continue printing successive layers. This limit will need to be factored into any volume packing approach.

This is where it becomes advisable to introduce some element of automation. A number of software tools are available to automate the volume packing process, AutoDesk NetFabb and Materialise Streamics being two of the most popular. These depend on sophisticated algorithms to optimise volume packing, the nature of which are closely guarded secrets. While they are certainly an effective solution to the challenge of volume packing, it’s important to note that they require both time and considerable computing power to run properly, which must be factored into
your project timelines.

Research is ongoing at institutions such as the University of Nottingham into new algorithms that will further refine these tools, incorporating elements such as machine scheduling, customer/factory locations and availability of materials. While these are still very much a work-in-progress, they will eventually help AM operations implement fully integrated solutions, where every area of the project workflow can be considered as part of a unified whole. This will help eliminate the disconnected, decentralised workflows that have burdened AM operations.

Quality Control

A 2016 report[^2] — produced in collaboration between the University of Nottingham, the University of Oxford, and Digits2Wigits — identified three key causes of build failure in 3D printing:

1. **Outright build failure.** A complete failure of the printing run, where all in-progress parts must be written off.

2. **Post-build part rejection.** Individual parts are rejected from the finished batch due to concerns such as structural errors or warping.

3. **Material failure.** The material used does not conform to the desired material specifications after printing. This typically resulted in all parts within the print run needing to be written off.

It is clear then, that AM operations require a three-step approach to quality control:

1. **Data preparation.** All project files must be checked before printing to ensure they are free of any errors in order to minimise any chance of build failure. There are a number of well-established data preparation tools available (see page 18), which should be utilised as a standard part of all production processes.

[^2]: [https://www.sbs.ox.ac.uk/sites/default/files/research-projects/3DP-RDM_report.pdf](https://www.sbs.ox.ac.uk/sites/default/files/research-projects/3DP-RDM_report.pdf)
Monitoring of the printing process. A number of software tools now provide real-time monitoring of the entire printing process. These include EOS’s EOSTATE monitoring suite, Sigma Labs’ PrintRite3D, and Materialise Inspector. These not only allow any potential errors to be caught and rectified immediately, potentially avoiding a complete build failure. As a bonus, this information can then be collated and analysed, providing a ‘big picture’ view of the printing operation, helping identify new opportunities for improvement.

Checking of all parts after printing. The final stage is a full inspection of all parts, to ensure all colours etc. have been captured correctly, that the parts are free of warping and structural errors, and that the material qualities are within specification. CT scanning is becoming increasingly popular among additive manufacturing specialists for this purpose, as it provides an accurate, comprehensive overview of a part’s interior and exterior, while freeing engineers of the need to manually inspect each individual part. If any post-processing is being utilised, a second inspection should take place, as many of these treatments will affect a part’s dimensions and material qualities (as we discussed earlier). As with monitoring systems, all this information can be collated to ensure errors are not repeated and any potential improvements can be implemented quickly.

Hybrid processes and complementary manufacturing techniques

The narrative that additive manufacturing will eventually replace traditional techniques has been a common one for a number of years now, but the more companies successfully implement AM technologies, the less convincing it becomes. Forward-thinking manufacturers are utilising multiple technologies as part of integrated project workflows, taking full advantage of each approach’s benefits, while avoiding the potential drawbacks.

For example:
Agile prototyping and efficient production. SLS can be utilised for the delivery of functional prototypes, while the actual production parts will be delivered using traditional methods. This dramatically streamlines the prototyping process, allowing multiple iterations of a part to be produced at reduced time and cost, while production can still utilise robust, well-established techniques.

Minimising the storage needed for emergency backups. Industries such as automotive and aerospace need replacement parts available at a moment’s notice, in case of emergencies. Due to the cost of producing limited-run or one-off parts using traditional methods, these are often challenging to produce and store. SLS allows fully functional replacement parts to be delivered on an as-needed basis, freeing up storage space and reducing material/production costs.

Minimising costs within traditional manufacturing approaches. When one considers injection moulding, for all its advantages, the moulds themselves are very time-consuming and expensive to produce. Furthermore, they can only be utilised a limited number of times, and so can easily become a significant ongoing expense. An increasingly popular strategy is therefore to create the mould using SLS. While they can still only be used a limited number of times, the speed with which they can be produced can translate into significant savings.

New opportunities for customisation. For luxury or limited-edition items, an element of customisation will inevitably be necessary. This has traditionally been an extremely time-consuming and expensive process, which has limited the degree of customisation manufacturers are able to offer their customers. The use of SLS printing can mitigate these concerns, allowing customised parts to be delivered at no additional costs, then combined with standard parts produced using other methods when required. This increased flexibility when it comes to offering customised parts could conceivably be turned into a powerful USP for manufacturers.
Paragon Rapid Technologies have successfully used SLS technology across a wide (and growing) range of industries, to deliver functional prototypes, low-volume production parts, and production support parts (i.e. gauges, jigs and fixtures). This has included industries such as automotive, architectural, medical, defence & security, and even the TV and film industry.
The architectural model shown above was produced for 3Cube, and uses a combination of SLS and SLA techniques. The design makes effective use of both technologies’ capabilities in order to illustrate both the interior and exterior of the design.

Further examples of Paragon’s work with SLS printing can be seen below.

www.paragon-rt.com
Conclusion

In this white paper, we have provided a comprehensive overview of the selective laser sintering process, the machines and materials involved and the steps needed to make full use of its capabilities in both prototyping and production.

We hope that this proves a useful reference work and inspires you to explore new applications for SLS across your own operations. With the increasing sophistication of SLS materials, machines and processes, we expect to see more companies successfully implementing this area of additive manufacturing as a key part of their service delivery. This will create a solid foundation on which to build the smart factories of the future, with multiple manufacturing techniques used to their full effectiveness as part of streamlined, fully optimised production workflows.

www.rpplatform.com