UNIT – 3

POWDER-BASED RAPID PROTOTYPING SYSTEMS

3D SYSTEMS' SELECTIVE LASER SINTERING (SLS)

Introduction:

Selective Laser Sintering is a rapid prototyping process that builds models from a wide variety of materials using an additive fabrication method. Selective Laser Sintering was developed by university of Texas Austin in 1987.The build media for Selective Laser Sintering comes in powder form which is fused together by a powerful carbon dioxide laser to form the final product.

In the last decade, the SLS® system has gone through three generations of products: the Sinterstation 2000, Sinterstation 2500 and the Sinterstation 2500^{plus} (see Figure 5.1). The latest and fourth generation SLS® system is the Vanguard^{TM}. The system is capable of producing objects measuring up to 380 mm (15 inches) length by 330 mm (13 inches) width by 380 mm (15 inches) in height, accommodating most rapid prototyping applications. The new VanguardTM system offers several significant improvements over the previous generation systems such as improved part accuracy, higher speed, smoother surface finish and finer resolution. A summary of the specifications for the VanguardTM si2TM is found in Table 5.1. The SLS® process is the only technology with the capability to directly process a variety of engineering thermoplastic materials, metallic materials, ceramic materials, and thermoplastic composites.

Principle

The SLS® process is based on the following two principles:

Parts are built by sintering when a CO_2 laser beam hits a thin layer of powdered material. The interaction of the laser beam with the powder raises the temperature to the point of melting, resulting in particle bonding, fusing the particles to themselves and the previous layer to form a solid.

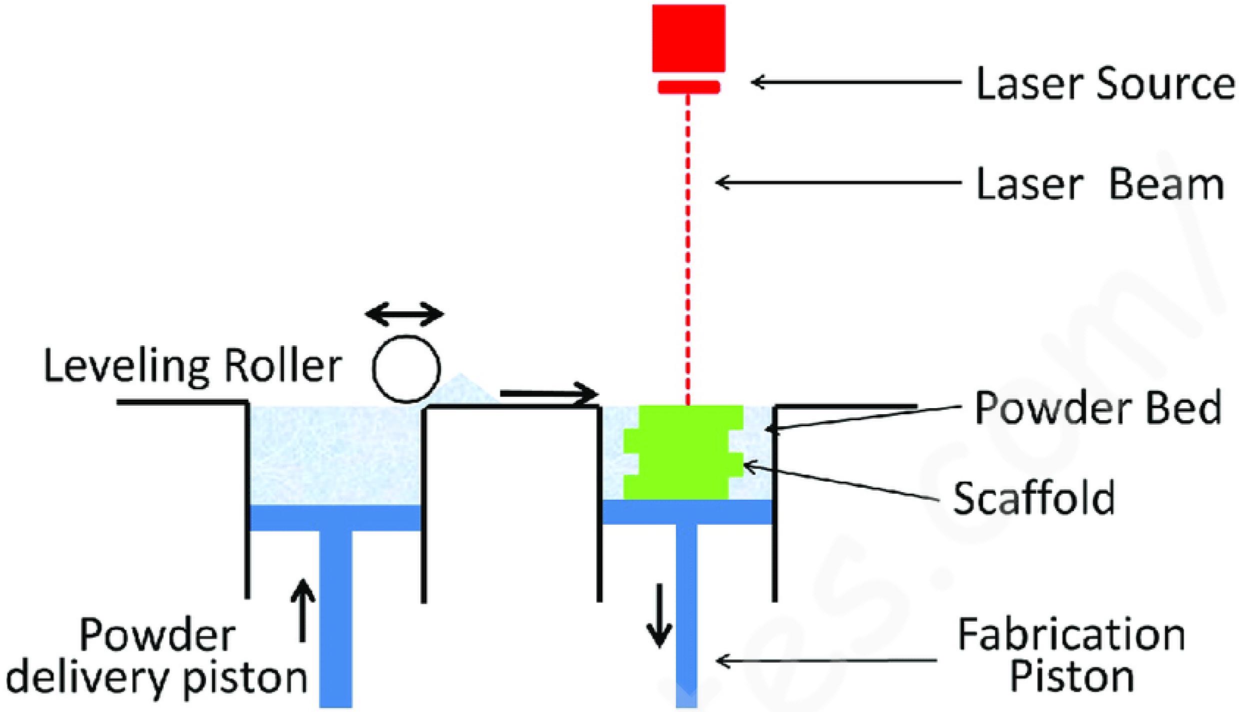
The building of the part is done layer by layer. Each layer of the building process contains the cross-sections of one or many parts. The next layer is then built directly on top of the sintered layer after an additional layer of powder is deposited via a roller mechanism on top of the previously formed layer.

The packing density of particles during sintering affects the part density. In studies of particle packing with uniform sized particles [3] and particles used in commercial sinter bonding [4], packing densities were found to range typically from 50% to 62%. Generally, the higher the packing density, the better would be the expected mechanical properties. However, it must be noted that scan pattern and exposure parameters are also the major factors in determining the mechanical properties of the part.

Model	Vanguard™ si2™ SLS®
Process	Selective Laser Sintering
Laser type	CO_2
Laser power (W)	25 or 100
Spot size (mm)	0.47
Maximum scan speed (mm/s)	7500 (standard beam delivery system) 10 000 (Celerity™ BDS)
XY resolution (mm)	0.178
Work volume, XYZ (mm × mm × mm)	370 × 320 × 445
Minimum layer thickness (mm)	0.076
Size of unit, XYZ (m × m × m)	2.1 × 1.3 × 1.9
Layering time per layer (s)	10 s
Data control unit	933 MHz Pentium III Windows 2000 OS
Power supply	240 V_{AC}, 12.5 kVA, 50/60 Hz, 3-phase

Purpose of Selective Laser Sintering:

- To provide a prototyping tool
- To decrease the time and cost of design to product cycle.
- It can use wide variety of materials to accommodate multiple application throughout the manufacturing process



The SLS® Process

The SLS® process creates three-dimensional objects, layer by layer, from CAD-data generated in a CAD software using powdered materials with heat generated by a CO_2 laser within the Vanguard™ system. CAD data files in the STL file format are first transferred to the Vanguard™ system where they are sliced. From this point, the SLS® is as shown in the above figure, below are the process steps:-

- A thin layer of heat-fusible powder is deposited onto the part-building chamber.
- The bottom-most cross-sectional slice of the CAD part under fabrication is selectively "drawn" (or scanned) on the layer of powder by a heat-generating CO_2 laser. The interaction of the laser beam with the powder elevates the temperature to the point of melting, fusing the powder particles to form a solid mass. The intensity of the laser beam is modulated to melt the powder only in areas defined by the part's geometry. Surrounding powder remain a loose compact and serve as supports.
- When the cross-section is completely drawn, an additional layer of powder is deposited via a roller mechanism on top of the previously scanned layer. This prepares the next layer for scanning.
- Steps 2 and 3 are repeated, with each layer fusing to the layer below it. Successive layers of powder are deposited and the process is repeated until the part is completed.

As SLS® materials are in powdered form, the powder not melted or fused during processing serves as a customized, built-in support structure. There is no need to create support structures within the CAD design prior to or during processing and thus no support structure to remove when the part is completed.

After the SLS® process, the part is removed from the build chamber and the loose powder simply falls away. SLS® parts may then require some post-processing or secondary finishing, such as sanding, lacquering and painting, depending upon the application of the prototype built.

The SLS® system contains the following hardware components:

Build chamber dimensions (381 × 330 × 457 mm)

Process station (2100 × 1300 × 1900 mm)

Computer cabinet (600 × 600 × 1828 mm)

Chiller (500 × 800 × 900 mm)

The software that comes with the Vanguard™ si2™ SLS® System includes the Windows 2000 operating system and other proprietary application software such as the slicing module, automatic part distribution module, and part modification application software.

Materials

In theory, a wide range of thermoplastics, composites, metals and ceramics can be used in this process, thus providing an extensive range of functional parts to be built. The main types of materials used in the Vanguard™ si2™ SLS® System are safe and non-toxic, easy to use, and can be easily stored, recycled, and disposed off. These are as follows

Polyamide. Trade named "DuraForm™", this material is used to create rigid and rugged plastic parts for functional engineering environments. This material is durable, can be machined or even welded where required. A variation of this material is the polyamide-based composite system, incorporating glass-filled powders, to produce even more rugged engineering parts. This composite material improves the resistance to heat and chemicals.

Thermoplastic elastomer. Flexible, rubber-like parts can be prototyped using the SLS. Trade named, "SOMOS® 201", the material produces parts with high elongation. Yet, it is able to resist abrasion and provides good part stability. The material is impermeable to water and ideal for sports shoe applications and engineering seals.

Polycarbonate. An industry-standard engineering thermoplastic. These are suitable for creating concept and functional models and prototypes, investment casting patterns for metal prototypes and cast tooling (with the RapidCasting™ process), masters for duplication processes, and sand casting patterns. These materials only require a 10–20 W laser to work and are useful for visualizing parts and working prototypes that do not carry heavy loads. These parts can be built quickly and are excellent for prototypes and patterns with fine features.

Nylon. Another industry-standard engineering thermoplastic. This material is suitable for creating models and prototypes that can withstand and perform in demanding environment. It is one of the most durable rapid prototyping materia222ls currently available in the industry, and it offers substantial heat and chemical resistance. A variation of this is the Fine Nylon and is used to create fine-featured parts for working prototypes. It is durable, resistant to heat and chemicals, and is excellent when fine detail is required.

Metal. This is a material where polymer coated stainless steel powder is infiltrated with bronze. Trade named “LaserForm ST-100”, the material is excellent for producing core inserts and pre-production tools for injection molding prototype polymer parts. The material exhibits high durability and thermal conductivity and can be used for relatively large-scale production tools. An alternative material is the copper polyamide metal–polymer composite system which can be applied to tooling for injection molding small batch production of plastic parts.

Ceramics. Trade named “SandForm™ Zr” and “Sandform™ Si”, these use zircon and silica coated with phenolic binder to produce complex sand cores and molds for prototype sand castings of metal parts.

Advantages

- Good part stability. Parts are created within a precise controlled environment. The process and materials provide for directly produced functional parts to be built.
- Wide range of processing materials. A wide range of materials including nylon, polycarbonates, metals and ceramics are available, thus providing flexibility and a wide scope of functional applications.
- No part supports required. The system does not require CAD-developed support structures. This saves the time required for support structure building and removal.
- Little post-processing required. The finishing of the part is reasonably fine and requires only minimal post-processing such as particle blasting and sanding.
- No post-curing required. The completed laser sintered part is generally solid enough and does not require further curing.
- Advanced software support. The New Version 2.0 software uses a Windows® NT-style graphical user interface (GUI). Apart from the basic features, it allows for streamlined parts scaling, advanced nonlinear parts scaling, in-progress part changes, build report utilities and is available in foreign languages

Disadvantages

- Large physical size of the unit. The system requires a relatively large space to house it. Apart from this, additional storage space is required to house the inert gas tanks used for each build.
- High power consumption. The system requires high power consumption due to the high wattage of the laser required to sinter the powder particles together.
- Poor surface finish. The as-produced parts tend to have poorer surface finish due to the relatively large particle sizes of the powders used.

Applications

The Vanguard™ si2™ SLS® system can produce a wide range of parts in a broad variety of applications, including the following:

- Concept models. Physical representations of designs used to review design ideas, form and style.
- Functional models and working prototypes. Parts that can withstand limited functional testing, or fit and operate within an assembly.
- Polycarbonate (RapidCasting™) patterns. Patterns produced using polycarbonate, then cast in the metal of choice through the standard investment casting process. These build faster than wax patterns and are ideally suited for designs with thin walls and fine features. These patterns are also durable and heat resistant.
- Metal tools (RapidTool™). Direct rapid prototype of tools of moulds for small or short production runs.

Sinter Bonding

In the process, particles in each successive layer are fused to each other and to the previous layer by raising their temperature with the laser beam to above the glass-transition temperature. The glass-transition temperature is the temperature at which the material begins to soften from a solid to a jelly-like condition. This often occurs just prior to the melting temperature at which the material will be in a molten or liquid state. As a result, the particles begin to soften and deform owing to their weight and cause the surfaces in contact with other particles or solid to deform and fuse together at these contact surfaces. One major advantage of sintering over melting and fusing is that it joins powder particles into a solid part without going into the liquid phase, thus avoiding the distortions caused by the flow of molten material during fusing. After cooling, the powder particles are connected in a matrix that has approximately the density of the particle material.

3D Printing (Z402 System)

Introduction:

Three-dimensional printing, or 3DP, is an MIT-licensed process, whereby liquid binder is jetted onto a powder media using ink jets to "print" a physical part from computer aided design (CAD) data. Z Corporation (Z Corp) incorporates the 3DP process into the Z402 system. The relatively inexpensive Z402 is directed toward building concept-verification models primarily, as the dimensional accuracy and surface roughness of the parts are less than higher end systems. The initial powder used was starch based and the binder was water based, however now the most commonly used powder is a new gypsum based material with a new binder system as well. Models are built up from bottom to top with layers of the starch powder and binder printed in the shape of the cross sections of the part. The resulting porous model is then infiltrated with wax or another hardener to give the part dexterity. The Z402 is the fastest modeller on the market, with speeds 5 to 10 times faster than other current rapid prototyping (RP) systems.

Models and Specifications

Z Corporation's latest products are the Z™400, Z™406 and Z™810 systems. The Z™400 System replaces the Z™402 System and has the same speed and performance as the Z™402 system but is configured for the entry-level and educational users. It does not come bundled with training or post-processing units. The Z406 3D Colour Printer builds parts three to four times faster than Z402C and utilizes four print heads as compared to Z402C. Its new print heads were developed by Hewlett Packard. This new machine is the first product of a cross-licensing agreement between HP and Z Corporation in the field of 3D printing. Z™810 System's large build volume and inexpensive build materials make it the fastest and the least expensive way to create large appearance prototypes. The system also offers a variety of finishing options including epoxy infiltration, sanding, painting and plating. The option of colour gives the user added information and aesthetics through the ability to incorporate colour directly into the part as it is being printed Table 5.3 shows the specifications of Z Corporation's 3D printers.

The Z400 3D printer is the entry-level concept modeling solution that delivers great models quickly and inexpensively. Models can be used for design verification, communication and as patterns for casting applications. Z Corporation offers a variety of materials for use with the Z400 3D printer. Beginning with two basic materials, a versatile and inexpensive starch-based powder and a high-definition plaster-based powder, infiltrants can also be added to satisfy a wide range of modeling needs.

The Z406 System is a premium 3D Printer with the capability of printing in full-colour, communicating important information about parts, including engineering data, labeling, highlighting and appearance simulation. It can print in six million colours and uses a new pigment system developed by Cabot Corporation for fuller and brighter colours. The software interface included with the new machine, MAGICS Z allows users to add colour information to STL files. It also includes a labeling option that lets users add text such as dates or revision coding directly to STL files. Figure 5.11 shows a photograph of Z Corporation's Z™ 406 3D printer.

Model	Z™ 400 3DP	Z™ 406 3DP	Z™ 810 3DP
Build speed	2 layers / min	Colour: 2 layers / min Monochrome: 6 layers / min	
Build volume (mm × mm × mm)	203 × 254 × 203	203 × 254 × 203	500 × 600 × 400
Layer thickness (mm)	0.076–0.254	0.076–0.254	0.076–0.254
Equipment dimensions (mm × mm × mm)	740 × 910 × 1070	740 × 910 ×1070	1020 × 790 ×1120
Equipment weight (kg)	136	136	210
System software	Z Corp.'s proprietary system software runs on Microsoft Windows 2000 and NT. VRML, ZCP, PLY and SFX file formats can be used for colour input. STL file format is accepted for monochrome parts.		
Materials	Starch and plaster formulations.		

Process:-

The machine spreads a layer of powder from the feed box to cover the surface of the build piston. The printer then prints binder solution onto the loose powder, forming the first cross-section. For monochrome parts, Z406 colour printer uses all four print heads to print a single-coloured binder. For multi-coloured parts, each of the four print heads deposits a different colour binder, mixing the four colour binders to produce a spectrum of colours that can be applied to different regions of a part.

The powder is glued together at where the binder is printed. The remaining powder remains loose and supports the layers that will be printed above.

When the cross-section is completed, the build piston is lowered, a new layer of powder is spread over its surface, and the process is repeated. The part grows layer by layer in the build piston until the part is completed, completely surrounded and covered by loose powder. Finally the build piston is raised and the loose powder is vacuumed, revealing the complete part.

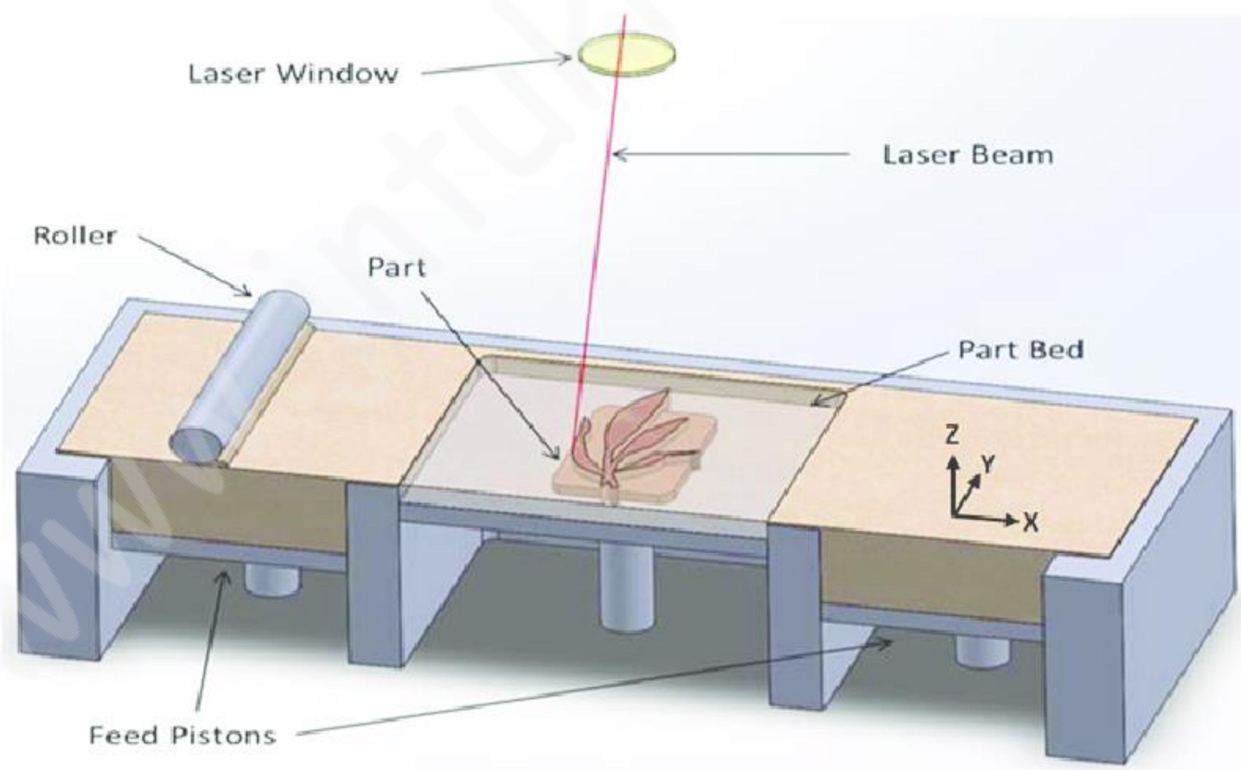
Once a build is completed, the excess powder is vacuumed and the parts are lifted from the bed. Once removed, parts can be finished in a variety of ways to suit your needs. For a quick design review, parts can be left raw or "green." To quickly produce a more robust model, parts can be dipped in wax. For a robust model that can be sanded, finished and painted, the part can be infiltrated with a resin or urethane

1. Build and Feed Pistons: These pistons provide the build area and supply material for constructing parts. The build piston lowers as part layers are printed, while the feed piston raises to provide a layer-by-layer supply of new material. This provides the z motion of the part build.

2. Printer Gantry: The printer gantry provides the xy motion of the part building process. It houses the print head, the printer cleaning station, and the wiper/roller for powder landscaping.

3. Powder Overflow System: The powder overflow system is an opening opposite the feed piston where excess powder scraped across the build piston is collected. The excess powder is pulled down into a disposable vacuum bag both by gravity and an on board vacuum system.

4. Binder Feed/Take-up System: The liquid binder is fed from the container to the printer head by siphon technique, and excess pulled through the printer cleaning station is drained into a separate container. Sensors near the containers warn when the binder is low or the take up is too full.



Post-processing:

Other than the Z402 system itself, there are several components needed for Post-processing of the part. For a concept model, the starch parts are generally infiltrated with paraffin wax, although more durable materials are available, from plastics to cyanoacrylate. Before infiltration, starch parts are fragile and must be handled with care. The following are the post processing steps for a part to be infiltrated with wax, with a total process time of about 15 to 20 minutes.

1. Powder Removal: After the parts are taken from the machine, the excess powder must be removed. With the system comes a small glove box with an airbrush system inside. The airbrush is used to easily and gently blow the powder off the part, and a vacuum cleaner is hooked to the glove box to remove the powder as it is blown from the part. (5 Minutes)

2. Heat for Infiltration: Once the powder is removed from the part surfaces, the part is placed in a small oven and heated to a temperature just above that of the infiltrate wax, to provide a wicking characteristic as opposed to coating. The part temperature for paraffin infiltrate is approximately 200°F. (10 Minutes).

3. Infiltration: Immediately after the part is heated, it is dipped for a few seconds into a vat of molten wax, then removed and placed on a sheet to dry. After drying the part is complete. (5 Minutes)

The actual post processing time will depend on the complexity of the part, the skill of the user, and the infiltrate used. Nonetheless, it is still minimal compared to some other RP processes.

Advantages

- High speed. Fastest 3D printer to date. Each layer is printed in seconds, reducing the prototyping time of a hand-held part to 1 to 2 hours.
- Versatile. Parts are currently used for the automotive, packaging, education, footwear, medical, and aerospace and telecommunications industries. Parts are used in every step of the design process for communication, design review and limited functional testing. Parts can be infiltrated if necessary, offering the opportunity to produce parts with a variety of material properties to serve a range of modelling requirements.
- Simple to operate. The office compatible Zcorp system is straightforward to operate and does not require a designated technician to build a part. The system is based on the standard, off the shelf components developed for the ink-jet printer industry, resulting in a reliable and dependable 3D printer.
- No wastage of materials. Powder that is not printed during the cycle can be reused.

- Colour. Enables complex colour schemes in RP-ed parts from a full 24-bit palette of colours.

Disadvantages

- Limited functional parts. Relative to the SLS, parts built are much weaker, thereby limiting the functional testing capabilities.
- Limited materials. The materials available are only starch and plaster-based materials, with the added option to infiltrate wax using the ZW4 Waxer
- Poor surface finish. Parts built by 3D printing have a relatively poorer surface finish and post-processing is frequently required

Applications

- It is used in manufacturing industries like Injection moulds, extrusion dies, direct metal components and blow moulding
- The technology is also suitable for repairing worn out metal tools.
- Used in rapid tooling