

**2002**

**AMPET CONFERENCE**

**Organic Binder Developments  
For Solid Freeform Fabrication**

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## **Introduction**

What is rapid prototyping? Why is it important in the design process? Before we address these two crucial questions and have appreciation for rapid prototyping, we shall address and understand the design process. That is what are the steps required to be taken by the designer to bring his/her idea to reality and consequently to profitability? Although the process from design-to-manufacture varies from business to business, a general pass involves (1) The concept, (2) Preliminary Design, (3) Preliminary Prototype Fabrication, (4) Short-run Production and (5) Final Production. Any new product or an improvement to an existing product starts with a concept. The motivation for the concept is generally based on a need or a gap that may exist in our current life style, technology, etc. Once it is established that the need for a particular product exists, the idea might be carried into the next phase of preliminary design. In this step, the designer may prepare a two dimensional drawings or even a Computer Aided Design (CAD) solid model of the part to be built. In this phase the design may go through several iterations as the designer determines the feasibility of the product through discussions with colleagues and co-workers and presenting it to management. Once the design has been given the “go”, a prototype must be fabricated to check out the design. Traditionally (Before Rapid Prototyping), this phase of the design was carried out either by hand working or machining the part. Both of these techniques require tremendous amount of man power and labor hours. The next stage of the process involves Short-run Production. This phase may be necessary to further proof a part before entering into final production. In this phase, from tens to hundred parts maybe produced and distributed for testing before entering the final production. Final step in the design involves the Final production. In this step, the parts are typically machined, injection molded or cast in large numbers depending on the design criteria and costs.

Traditionally the process of design-to-manufacture took several months or even years to fully mature. That is due to the overhead associated with iterations in steps (2) and (3). In that, the designer gave the preliminary design to the machine shop. Depending on the complexity of the part, this may take several days or even weeks to build the part. Then the part may go back to the designer for approval and verification. Then there may be additional modifications to the design which much be corrected in the prototyping phase. Rapid prototyping therefore is the process of replacing this time consuming process with a much more efficient and faster process. Rapid Prototyping (RP), refers to the layer-by-layer fabrication of three-dimensional physical models directly from a computer aided design (CAD). This additive manufacturing process provides designers and engineers to literally print out their ideas in three dimensions. The RP processes provide a fast and inexpensive alternative for producing prototypes and functional models as compared to the traditional routs for part production. The advantage of building parts in layers is that it allows you to build complex shapes that would be virtually impossible to machine, in addition to the more simple designs. RP can build intricate internal structures, parts inside parts, and very thin-wall features just as easily as building a simple cube. All of the RP processes construct objects by producing very thin cross sections of the part, one on top of the other, until the solid physical part is completed. This simplifies the three dimensional construction process in that the essentially two dimensional slices are being created and stacked together. For example, instead of trying to cut out a sphere with a detailed machining process, stacks of various sized “circles” are build consecutively in the RP machine to create a sphere with ease.

### History of Rapid Prototyping

RP stems from the ever-growing CAD industry, more specifically, the solid modeling side of the CAD. Solid modeling is the branch of CAD that produces true three dimensional objects in electronic format. A solid model has volume and is fully enclosed. Before solid modeling was introduced in the late 80's, three dimensional models were created with wire frames and surfaces. A wire frame is an approximate presentation of a three dimensional object. Not until the development of true solid modeling could innovative processes such as RP be developed. The first RP system was developed by Charles Hall in 1986, who also helped found 3D systems. This process, called stereolithography, builds objects by curing thin consecutive slices of certain ultraviolet light sensitive liquid resins with a low power laser. There are now many national and international companies manufacturing and selling RP processes. Among these machines are:

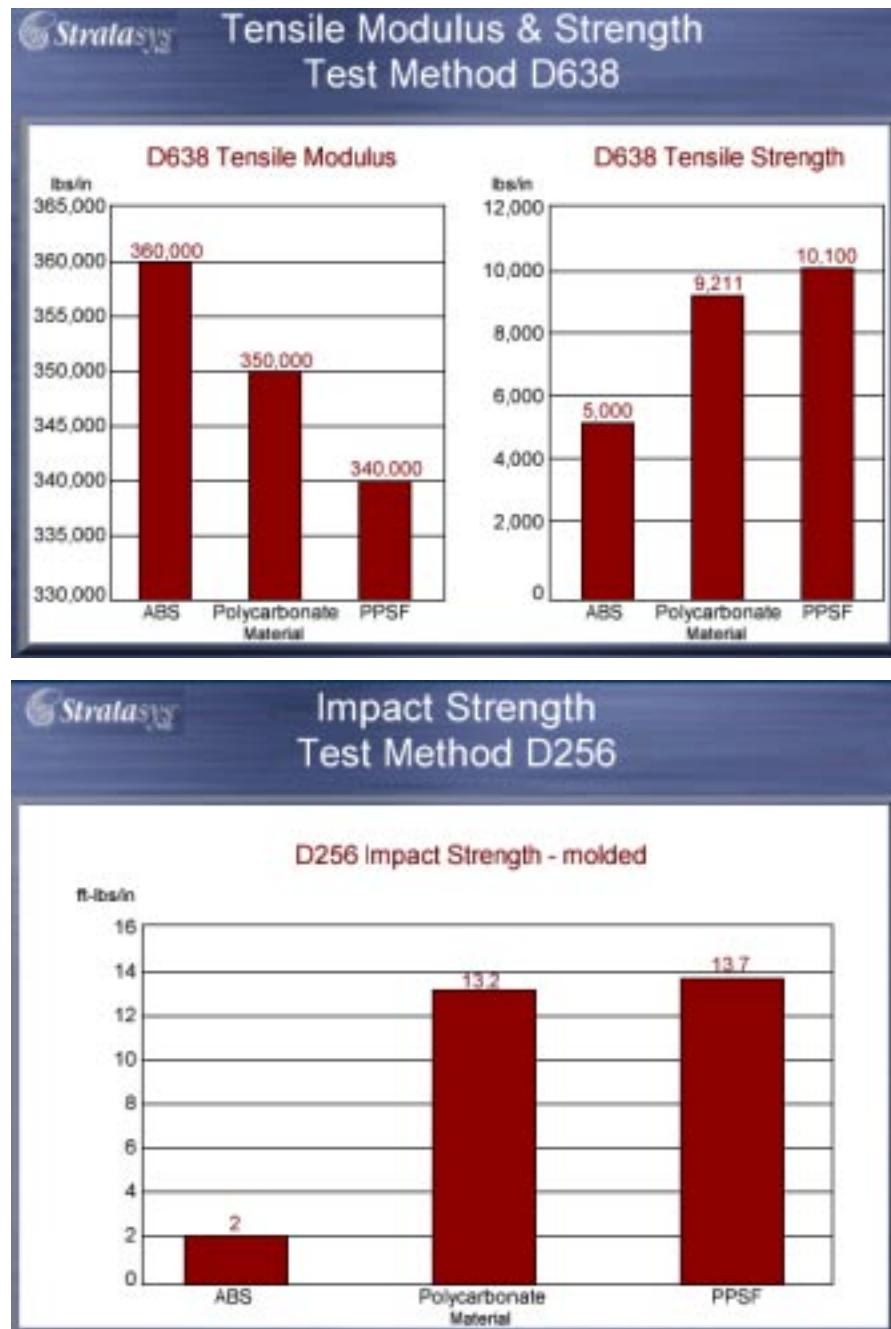
- (1) JP-System 5 (JP5), By Schroff Development- This process builds models from CAD Data using label paper and a knife plotter. JP5 is a simple and inexpensive modler for creating rough 3D models.
- (2) Ballistic Particle Manufacturing (BPM)- This process involves firing droplets of molten wax from a moving jet onto a stationary platform.
- (3) The Model Maker (MM), and Rapid Tool Maker (RTM) by Sanders Prototype: This process produces highly accurate wax patterns using ink-jet printing technology with molten wax.
- (4) Multi-Jet Modeling (MJM) used by 3D Systems, Inc.: This process uses inkjet printing technology with many jets enclosed into a single print head to produce concept models.
- (5) Direct Shell Production by Soligen Inc.: Uses Binder printing technology developed by MIT. The binder is printed by layers of ceramic powder to produce investment shells directly from CAD.
- (6) The Z402 System by Z-Corp: Also uses MIT 3D printing technology to build very fast concept models from a starch like material
- (7) Fused Deposition Modeling (FDM), by Strasys, Inc. Produces models from wax or ABS Plastic using motion control and extrusion technology similar to a hot glue gun.
- (8) Laminated Object Manufacturing by Helisys, Inc. Builds physical models by stacking sheets of paper or plastic material and cutting away excess material with laser.
- (9) Stereolithography, by 3D Systems, Corp. Is the oldest RP system and builds models by curing epoxy resins with a low power laser.
- (10) Selective Laser Sintering, by DTM can build with a variety of materials and works by selective melting together powder with laser into a desired shape.
- (11) Laser Engineered Net Shaping, by Optomec Design Co., builds parts directly by metal powders by fusing the powder together with a laser beam.

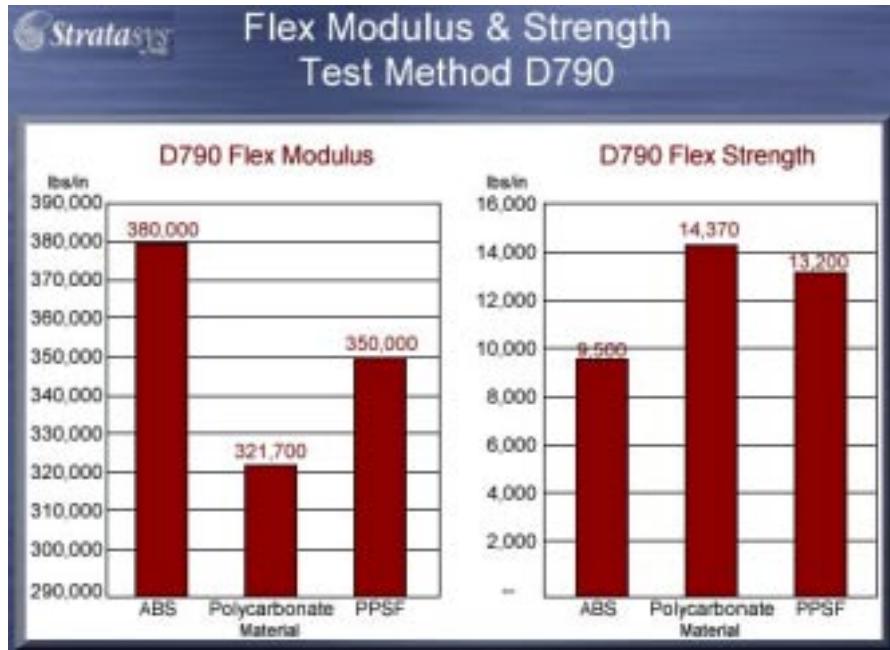
In the course of past few years some of these machines have gained considerable speed and accuracy such as Selective Laser Sintering (SLS). The NASA Marshall's National Center for Advanced Manufacturing RP center has variety of these machines available. A considerable amount of research is directed towards this area at this center. Among the goals of this center is to produce actual functional parts from metallic materials using current technologies such SLS machines. Potentially there exists a strong market for this technology. Among many applications of this technology is to build actual parts on demand on space for space vehicles rather than transporting the spare parts with the space vehicle.

## Commercial Binder Developments

### Fused Deposition Modeling (Stratasys)

The Titan system by Stratasys, Inc. has an internal oven to process high temperature polymers. Polycarbonate and Poly-Phenyl Sulfone (PPSF) are currently the two materials offered in addition to the previously offered ABS (acrylene butadiene styrene). The associated properties of each material, as published by Stratasys, Inc. are demonstrated in the following figures.





### Three Dimensional Printing (Z Corp)

Zcorp's latest powder/binder combination for the 3D Printer provides a part that is easier to handle right out of the machine. Microstone (ZP100) is a plaster based material with about 10MPa strength, and can also be infiltrated with urethane or cyanoacrylate to be very tough and strong. A new material soon to be release is the Zcast system, which provides sand-like core and cavities for investment casting.

### Selective Laser Sintering (3D Systems)

The Latest Tooling Material from 3D Systems for the Selective Laser Sintering Process is SLS LaserForm ST100. LaserForm is a polymer coated steel which is fused together by the SLS laser by melting only the polymer element of the powder. The material must then go through a burnout and infiltration process (24 hours), which includes removing the polymer binder and wicking with a secondary bronze material. Resulting parts are showing strengths and utilization comparable to stainless steel. The following figure shows the properties of SLS Laserform.

Mechanical Properties	UNITS	SLS Laserform TEST METHOD	
Tensile - Yield strength (0.2%)	MPa	ASTM E8	305
Strength	MPa	ASTM E8	510
Elongation	%	ASTM E8	10
Young Modulus	GPa	ASTM E8	137
Compression - Yield Strength (0.2%)	MPa	ASTM E9	317
Hardness - Rockwell "B"			
as infiltrated	-	ASTM E18	87
as machined	-	ASTM E18	79

## Research Binder Developments

The process of Selective Laser Sintering involves the acquisition of a layer of a part from a CAD drawing and fusing a powder with laser beam only in the regions where solid is present. This is a highly accurate process and the parts generated in this manner are extremely durable. The objective of this research effort is to establish parameters for the SLS Machine for producing functional parts from Titanium Alloys.

### Methodology Adopted for the Laser Sintering Technique

There are primarily three parameters that dictate the quality of the part generated via SLS processing. These parameters are: (1) Laser Power, (2) Part Bed Temperature at which the part is built, and the (3) Layer Thickness for the part to be formed. At the first step of this process we formulated a test matrix which spanned the laser power from 5 to 40 watts, layer thickness from 0.003 to 0.012 and the part bed temperature from 40 to 100 C. This was necessary to zero in on the three parameters.

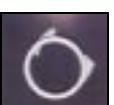
### Results

As a result of this research effort, the following parameters were selected:

- (1) part Bed temperature was to be maintained around 100
- (2) Laser power was to be set around 30 Watts
- (3) Powder layer thickness was to be set to minimum of 0.003 However since no satisfactory results were obtained here it was decided -to allow two passes of the roller on the powder before adding the powder to the part bed. At first the samples were tested -using the binder alone. Once the parameters for the binder was selected it was applied to the actual titanium alloy. A summary of the results is given in the following table (1).

Table 1. Summary of Results for the binder material

No.	Observations made	Photo
1	The sample was built to the height of 0.125 inches. Sample was run once with the thickness of 0.006. Shifting was present in the part. This is perhaps due to the shear force of roller on the powder. Part appeared to be very brittle and unstable.	

2	The sample was built to the height of 0.125 inches. The bed temperature was increased to 100 C. Sample was run twice with the thickness of 0.003. Shifting was still present in the part. Part appeared to be very brittle and unstable; however, the integrity of the part appeared to be a slightly better than the previous runs.	
3	It is observed that the quality of the parts appears to be highly dependent on the part bed temperature. The part appeared to be more stable by increasing the temperature to 100 C. The parts still appear to be sheared off, so in the next run the powder will be added on top of the part instead of front of it. The temperature will be raised to 110 C.	
4	The sample was built to the height of 0.25 inches. The bed temperature was set to 100C. Sample was run once with the thickness of 0.003. In this run we sprayed a layer of powder on top of the part area so that shear force was minimized. Shifting was still present in the part but was corrected after several layers. Part appeared to be more stable than the previous runs. This might be attributed to the increase in surface contact area or binding area due to elimination of shifting.	
5	The sample was built to the height of 0.20 inches. The bed temperature was set to 100 C. Sample was run once with the thickness of 0.003. In this run we sprayed a layer of powder on top of the part area so that shear force was minimized. Shifting was eliminated entirely. Part appeared to be more brittle than the case where laser power was set to 40 Watts.	

## **Resources**

The machine used for this project was the Selective Laser Sintering Machine (SLS2000) located in the RP laboratory of the NCAM at NASA Marshall. Material used in the research is the Titanium alloy. There are two software that drive the SLS process: Build Software and Sinter. The build prepares the stl files and gives a visual representation of the location of each part in the Part bed. The Sinter software is the driver software for the SLS machine, in which all the operations and control such as piston movement, loading and unloading the powder, movement of the roller, and latching and unlatching the doors for the machine are performed via this software.

## **Conclusion**

1. The parameters established for this process are Part Bed Temperature of 100 C, Laser power of 25 to 30 and layer thickness of 0.003 or lower if possible.
2. Due to rarity of sample all cases were conducted in the presence of Oxygen. This might contribute to "vaporizing" The binder material before it is sintered.
3. It is essential to eliminate or at least minimize shifting. Shifting of layers causes decrease in the binding surface area and hence adds to instability of the part.

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