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Truly Functional Prototypes

Real plastic materials help engineers create functional prototypes that get products to market faster.

MOST PROTOTYPES TODAY UNDERGO AT least some functional testing. In fact, according to *Wohlers Report 2005*, manufacturing industries desire functional prototypes more than any other kind (see **Graph 1**).

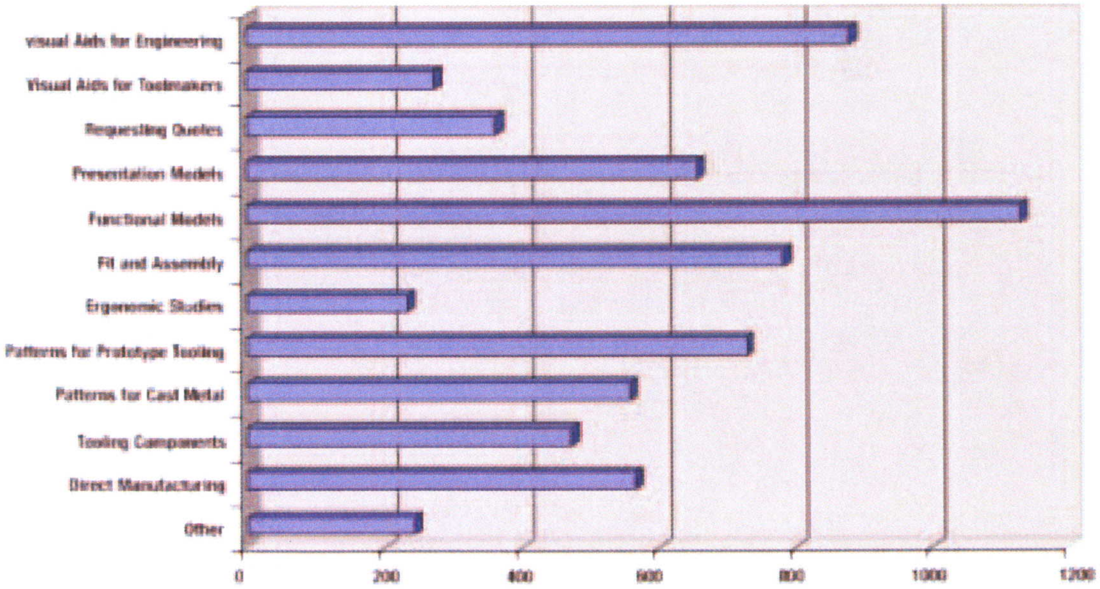
Selecting a product's material is one of the most important decisions an engineer makes in the development of a new product. The right material allows product designers to effectively test prototypes for everything from structural integrity to heat resistance. As a result, nearly 80 percent of *Time-Compression Technologies* readers participating in the 2005 Service Provider Survey (November/December 2005) rated material as "very important" when selecting a service provider.

In an effort to accurately simulate the physical properties of production products, design engineers are using several popular additive methods to produce durable prototypes. They build the parts one layer at a time out of a growing selection of proprietary materials. Subtractive Rapid Prototyping (SRP) is another important process for creating functional prototypes.

SRP starts with a homogeneous block of nonproprietary plastic and mills away unwanted material to reveal the desired part. The process produces low-cost prototypes that are structurally, thermally, and electrically nearly identical to the final production part/product. An extensive material selection includes popular engineered plastics such as ABS, Delrin, and nylon—often the same material used in the manufactured product. The SRP process also verifies a part's manufacturability, which reduces the number of design iterations and gets the product to market faster.

Surprisingly, many thought leaders in the rapid prototyping industry often leave SRP out of the family of RP processes. As a result, design engineers often have a difficult time learning about the benefits of SRP via industry organizations, trade shows, and engineering publications. Hence, picking the best technology for producing functional prototypes requires us to look beyond the industry experts.

This article investigates the structural differences between prototype plastic parts and final production injection-molded parts. In addition to material properties, the article examines the major RP



Graph 1: How RP Models are Used Source: Wohlers Associates, Inc.

processes and the surface finish and dimensional accuracy that each one achieves. These elements are all vital to producing truly functional prototypes that help get products to market fast … and start making money.

Material Properties

A good prototyping process should help, not hinder product development. Systems using SRP technology help designers make prototypes that behave in a fashion that is physically similar to production injection-molded parts. The part typically performs just like the manufactured product.

Johnson & Johnson, for example, uses an SRP system to mill functional toothbrush prototypes out of actual toothbrush plastic. Because the finished prototype is truly functional, it can undergo in-vivo testing for hand fit, reach, and handle deflection. Such effective testing allows Johnson & Johnson to evaluate a model's characteristics early in the design process and get products to market quickly with lower development costs.

A larger selection of materials to choose from makes it easier to create prototypes that meet FDA and other special government requirements, including UV resistance, bending strength, surface hardness, electrical conductivity, etc. This is particularly important for biomedical and food processing products, where biocompatibility and chemically inert properties are critical. Meeting requirements such as these is a critical step in developing a product and reducing time to market.

The non-isotropic properties of most additive RP materials cannot help designers make good material selections. Building parts one layer at a time creates residual stresses. While some residual stress can be removed though annealing, the part is still far from isotropic. As a result, parts often lack dimensional accuracy due to differing coefficients of thermal expansion in x, y, and z directions.

The Stratasys™ Dimension, for example, is one of the most popular additive systems for creating functional prototypes. Using FDM (Fused Deposition Modeling™) technology, the system melts and extrudes a proprietary ABS and/or polycarbonate material one layer at a time to achieve the desired shape. Among all of the additive processes, FDM's ABS-like material is one of the strongest and most durable. Yet, FDM parts are still only 65 to 80 percent as strong as real injection-molded parts. Thermal testing is also unpredictable due their non-isotropic coefficient of thermal expansion. When heated, these parts expand differently in x, y, and z directions.

SLA (Stereolithography®) is a favorite of the aerospace industry for creating complex prototypes with fine detail. By tracing a laser beam on the surface of a vat of liquid photopolymer, designers can quickly build plastic parts one layer at a time. The prototypes are made of rigid plastic and other ABS-like materials. They often test these prototypes in a wind tunnel or use them for fit and form testing. Alas, like FDM the materials do not accurately reflect the properties of production plastic parts.

SLS (Selective Laser Sintering®) prototypes are similar to SLA prototypes. After a designer slices a CAD model into thin layers, the SLS machine uses an infrared laser to sinter the layers together with a variety of nylon and metal powders. Models can be produced from flexible plastics as well as rigid ones. SLS technology can rapidly produce durable, functional models for a wide variety of applications. Surface finish and dimensional accuracy, even with recent improvements, are still not among SLS strong points.

3D printers use a thin layer of starch/sugar powder and a binding chemical to build models one layer at a time. This specially formulated composite powder is enhanced with a variety of proprietary plastic materials to match the desired application. For producing functional prototypes with its ZPrinter® 310 Plus, Z Corporation offers a plaster material with numerous additives that maximizes surface finish, feature resolution, and part strength. On the down side, these prototypes are often brittle and grainy with a rough surface finish.

Precision and Surface Finish

In addition to material selection, precision and surface finish play a vital role in creating functional prototypes. When parts have good dimensional accuracy and a smooth surface, they perform better as fit and assembly check models—the third most popular type of prototype needed by engineers (**see Graph 1**). Fit/assembly models enable designers to effectively simulate snap fits, fluid tight seals, and thermal and electrical conductivity between parts.

Due to the dimensional variance inherent to the layer-on-layer build method, additive systems produce prototypes with layered, stair-stepped surfaces. The additive layer process is the major reason for non-homogeneous material properties, layer-to-layer adhesion issues, material phase-change shrinkage, and porous surfaces. As a result, these parts tend not to perform well in fit and assembly checks. Conversely, SRP models made from engineered plastics yield a smooth, nonporous surface finish and have no need for chemicals or post-finishing work. These models perform better in fit and assembly checks and accurately represent the final manufactured part.

Price

Cost varies widely for additive systems, ranging from $30,000 for entry-level 3D printers to $500,000 SLA machines. The requirement for proprietary materials and expensive maintenance contracts raise the operating costs significantly. This ongoing expense can be substantial over time and significantly affect the ROI for the capital equipment. SRP systems usually cost between $3,000 and $30,000. They also have the lowest operating expenses thanks to their proven technology, reasonable maintenance costs, and a wide choice of non-proprietary materials.

SRP Versus VMCs

Desktop SRP systems have much in common with production VMCs (vertical machining centers). They both start with a solid block and mill away unwanted material to reveal the desired part. They can both handle a wide variety of commercially available engineered plastics such as ABS, Delrin, and nylon. SRP and VMC systems also benefit from years of development of precision motion control, technologically refined AC servomotors, look-ahead processing algorithms, simultaneous four axis controls, and automatic tool changers.

Beyond that, SRP systems and production VMCs have several important differences. SRP systems are developed to help design engineers quickly create prototypes. VMCs are optimized for cutting metal parts and steel tooling. As a result, SRP systems are much better suited for use in an office setting. Small enough to fit on a desktop or a cart with casters, they fit through standard doorways and plug into regular wall sockets instead of commercial 3-phase outlets. They run quietly without any messy and odorous liquid cooling and filtering systems.

SRP systems are also easy to operate. Manufacturers have seamlessly integrated SRP devices with CAM software optimized for prototyping. More than anything else, this interoperability is responsible for bringing machining technology from the shop floor to an office design environment.

The Right Tool

It's an exciting time for the entire RP industry, additive and subtractive technologies alike. Service provider revenues are up once again, and the total number of prototypes produced is at an all-time high. Yet, whether manufacturing industries are booming or not, it's important to use the right tool for the job.

For producing functional prototypes, material selection is the most important factor. Among additive processes, FDM and SLS certainly have the most to offer. FDM's ABS-like material is strong and durable. SLS's nylon- and metal-based material is strong and heat-resistant. Yet, these expensive proprietary materials do not yield the same functionality as real plastic materials.

SRP cannot produce every prototype, as the process has difficulty with some complex geometries and deep undercuts. At the same time, it's worth noting that some parts that SRP cannot produce are either not manufacturable or extremely expensive to mass produce. For the vast majority of jobs, however, SRP produces the most functional and cost-effective prototypes.

There's just no substitute for using real production plastics. They enable engineers to accurately test material properties and produce prototypes with superior precision and dimensional accuracy. The bottom line is that products get to market and start making money sooner. **TCT**

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