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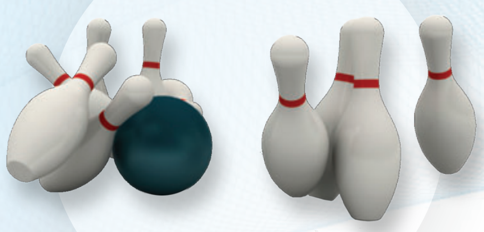
Journal

OF RAPID INJECTION MOLDING AND CNC PROTOTYPING

REAL PLASTIC



From its beginning as a substitute for other materials, plastic has come into its own as a unique class of materials with a vast range of capabilities.

IN THIS ISSUE:

What is Real?

"How tall was King Kong?" demands director Eli Cross of his protege in the 1980 film *The Stunt Man*. The answer, of course, is three feet six inches; the Kong we saw on screen was merely a model used to portray the towering ape on-screen. Likewise, George Lucas' Death Star in Star Wars was a model of rather mundane dimensions, cinematically enhanced to represent the Empire's planet buster.

We all use models every day, and for good reason. Until we can buy the cars or fly the planes of our dreams, we own them in the form of models. Because we cannot fit the route from home to Disney World into our cars, we use maps (or MapQuest® or Google Earth®) to view it in miniature. Besides being small enough to manipulate, these scaled representations have the additional advantage of eliminating the unnecessary—gas tanks for the car models, or roadside billboards from the map—to provide only the necessary functionality. King Kong lacked heart, lungs, and just about everything else one would expect to find inside a real gorilla, and the Death Star contained, one suspects, nothing but Styrofoam®.

> "… it just makes sense to make the far smaller investment in prototyping that will get you as close to the eventual production product as possible."

When it comes to prototypes, we have to ask exactly what is "necessary." The answer, of course, depends on the stage of development you are in. As an aid to thought, sketches on the back of an envelope may be all you need. When you are trying to fit parts together, any quick-and-easy concept modeling process may serve your purpose. But when it comes time for functional testing, you need more than size and shape. You need performance that is as close as possible to that of your finished product. And if you are going to market-test your prototype, it has to look and feel like the finished product as well.

In short, before you commit to costly full-scale marketing and production, it just makes sense to make the far smaller investment in prototyping that will get you as close to the eventual production product as possible. Which brings us back to the question: "What, exactly, **IS** real"?

"Real" prototype plastic parts have three components: material, design and process. With hundreds of resins on the market, it is almost impossible to intuit the performance of one resin by looking at another. So any so-called "real" prototype has to be made from the exact material you plan to use in production ("ABS-like" will not suffice).

It continues to cosmetics; in today's design-savvy markets, you cannot predict user reaction to a color or surface finish without actually testing them. For this reason, your prototype parts need to convey your design accurately if you are going to make decisions based on what people have to say about them.

And finally, the prototyping process can be critical as well, both from a material properties and manufacturability standpoint.

In this issue of the Journal, we look at plastic as a material as well as the processes by which it can be turned into "real" prototypes. As always, we hope you find the presentation useful and engaging.

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The Lifecycle of Plastic — Impacts on business and the economy

Over the last sixty years, plastic has become one of the most common materials in the man-made world. As a result, we take it for granted, thinking little about its origins and less about its cost, especially since it costs less than most of the materials it has replaced. At the same time, aside from recycling our pop bottles, we don't think much about where our plastic goes once it has served its purpose. But, as the cost of petrochemicals skyrockets and concern with the environment continues to grow, we'll have to think more about plastic's origins and destinations, both as consumers and as producers of plastic components.

It wasn't long ago that we were alarmed by petroleum prices of $50 a barrel. As this is being written, that price is approaching $100 a barrel and still climbing. Ask most consumers how petroleum prices affect them and they'll cite transportation; not surprising, considering that half of our petroleum is refined into gasoline. But the cost of gas is still small compared to the cost of the cars we drive, and smaller still compared to the wages we earn at the jobs we drive to. Resin, on the other hand, typically represents three-quarters of the cost of a plastic part, making the cost of the part very sensitive to oil prices.

What's a resin user to do? First, we need to recognize that the problem isn't going away. As far back as 1956, geologist M. King Hubbert predicted a near-term mathematical peak in oil production, and while experts still argue over whether "Hubbert's Peak" is approaching or has already passed, few dispute its existence. Meanwhile, world demand continues to grow. We can assume that consumers will bus, carpool, or downsize their vehicles before they cut back on plastic purchases, but it's not too early to start thinking about controlling material costs.

Obviously, the purchasing department will do its share, but designers will have a role as well. Choice of materials will be more critical than ever. So will design as a means of achieving maximum performance using no more material than is absolutely necessary. And since per-piece material savings will be multiplied by thousands, or even millions, when parts go into production, careful performance testing in the prototyping stage will be critical.

"Over the last sixty years, plastic has become one of the most common materials in the man-made world."

Finally, while the technology is still young, chemists are beginning to produce plastics that do not rely directly on petrochemicals. Among the most promising is polylactic acid (PLA), a thermoplastic aliphatic polyester derived from corn or sugarcane. The material is also of interest for its possible benefits at the back end of plastic's lifecycle, where PLA shows some promise of biodegradability. While it can not yet be broken down in your backyard compost heap, it does have potential in that arena that traditional resins lack.

As always, engineering is an exercise in overcoming challenges, and anticipating the challenge is the first step in the process. Our First Cut Prototype and Protomold divisions are here to help with design guidance you can use to maximize part manufacturability, as well as the prototype parts you can test to make sure you've achieved the required functionality.

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Engineering Trade-offs

How to meet identified needs with plastic

We may call them "our favorites," but in fact they are your favorites. They help fill the bulge under the bell curve. They constitute the royal court at prom; they are the popular kids everybody knows.

They are the double handful of thermoplastics that make up the vast majority of plastic items we see and use every day. Sure, there are other more specialized resins—thousands of them—with unique capabilities and, as often as not, strict limitations, special handling requirements, and mind boggling price tags. But these nine are among the mainstays: relatively accessible, relatively easy to use, and relatively affordable.

If you were one of the lucky thousands who got your hands on one of Protomold's popular nine-piece resin puzzles, you can follow along with the assembled cube (or the jumble of molded puzzle pieces) on your desk.

1. **High-density polyethylene (HDPE)** is notable for its flexibility, chemical and impact resistance, and low cost. It lacks heat resistance and doesn't have great dimensional accuracy, but these are not required in applications like food containers, detergent bottles, vehicle fuel tanks, and water and gas pipes, all applications in which HDPE is used.

2. **Polypropylene (PP)** is not as tough as HDPE, but it is less brittle. It can also withstand more heat, allowing it to be sterilized for medical and laboratory use. It is sometimes used as a less expensive substitute for engineering plastics like ABS and PET.

3. **Acrylonitrile butadiene styrene (ABS)** boasts excellent impact resistance, moderate strength, and good cosmetic appearance. It has poor resistance to heat and is somewhat more expensive than PP or HDPE, but is useful in applications like golf-club heads, protective headgear, and LEGO® blocks.

4. **Polycarbonate (PC)** has excellent strength and impact resistance across a range of temperatures. It is available in a visually clear grade. It is not very resistant to chemicals and is moderate to high in cost. Its strength and clarity make it suitable for eyeglass lenses and as a glass replacement in applications like automotive headlights. Some grades are also used in medical applications.

5. **PC/ABS** blend combines the strength and impact resistance of polycarbonate with the cosmetics, and processibility of ABS to offer a moderately priced resin suitable for a variety of applications, including automotive parts and electronic housings.

6. **Acetal (polyoxymethylene)**, or POM, boasts high strength and lubricity making it suitable for bearings and the stylii used on PDAs. It is highly resistant to hydrocarbons and organic solvents. It is sometimes used as a metal replacement and has recently been used in the manufacture of musical instruments, replacing both metal and wood.

7. **Polybutylene terephthalate (PBT)** is tough and flexible in its unfilled form and can be strengthened significantly with the use of glass fill. It shrinks little, but can warp significantly with glass fill. It has excellent electrical properties and is used as an insulator.

8. **Nylon (PA66)** is strong and resistant to chemicals except strong acids and bases. It flows well, making it useful for molding thin part geometries. Nylon is subject to warping, is moderate to high in price, but wears well and is used in a variety of applications including auto and machine parts.

9. **33% glass-filled nylon (PA66 GF33)** shares many of nylon's characteristics, but has almost twice the strength. It lacks some of nylon's non-lubricated wear properties and can be abrasive to other materials.

For more information on these and other resins, go to **www.protomold.com/DesignGuidelines_ResinInformation.aspx.**

Life After Prototyping

Consider the process

It's the call you hoped you'd never get. You've spent months developing a product: researching customer needs, engineering to meet those needs, and building mockups. You've tweaked the design, developed a marketing strategy, and tested with focus groups. Maybe you've even started taking orders. Then the phone rings.

It's a call from the manufacturing floor—down the block, in another state, or somewhere overseas—with those four little words that are going to ruin what could have been a very good day. "We have a problem."

It may be something small, a minor mistake in a single component of a larger system. But until that mistake is rectified, your entire product launch is on hold. If the solution entails remaking injection molds, "hold" could last for weeks or months. And in a competitive market, those weeks could cost you hundreds of thousands of dollars, or even more. Ideally, this sort of problem is caught and rectified during product development, but that's not always easy. And if you've used prototyping processes that don't match your production processes, you've introduced even more variables into the problem.

Injection molding continues to be the most commonly used high volume plastic production method used today. So if you want to accurately prototype a part that will be injection molded production, you need to use an injection molding prototyping process. Additive processes like SLA, FDM, or stereolithography won't tell you how and where your part will warp, and they can't predict flow defects or knit lines. Nor can they tell you how easily the part will be ejected from the mold. In fact, their greatest strength, the ability to make any imaginable geometry, can be their greatest weakness if they fail to identify features that simply cannot be injection molded in production.

So if RP processes are a poor substitute for injection molded prototypes, why not just digitally simulate the process and take the lessons learned straight to production? The answer is that there is no simulation that is accurate enough.

So if you want to accurately prototype a part that will be injection molded production, you need to use an injection molding prototyping process.

What happens inside an injection mold is a highly complex interaction of a particular resin, a specific geometry, thermal effects and the motion of one or more mold segments when the part is ejected. Good analysis and simulation tools such as Protomold's ProtoFlow® can make a prediction, but (like the weather) there are too many variables to be able to entirely rely on any simulation. There is simply no substitute for really making some parts to prove everything works as expected before making a large tooling investment.

Of course, additive processes and simulation tools have their place in the design process, but they don't actually prove out the production process you'll be using to take your product to market. The only sure way to know how a particular part will perform in a given resin is to inject that resin into an actual mold. The good news is that Protomold helps you do just that.

There is simply no substitute for really making some parts to prove everything works as expected ...

The better news is that, if Protomold's rapid injection molding identifies manufacturability issues, you can fix them without missing your deadlines and before you invest in full-scale manufacturing—one more reason to prototype with real plastic and real processes.

Ways in which plastic is substituted for other materials

There's nothing new about plastic as a substitute for other materials. From its very beginnings, plastic took the place of whalebone, tortoiseshell, wood, and stone. The reasons for substitution were simple: availability and cost. Mixing up a vat of combustible celluloid had its risks, but they were small compared to those of hunting whales in tiny boats. Plastics were cheap compared to the semiprecious stones they replaced in costume jewelry, and they were easier to work than wood or stone.

Today, plastic still makes financial sense, but it often replaces other materials on the basis of performance as well. In the example shown here (Figures 1 & 2), a single plastic part replaced seven metal components: top and bottom brackets, a bearing assembly, and four screws. The part, a clip-in shaft bearing, carries the rotating paper-feed shaft in a printer. To be molded as a single part, it had to be totally redesigned, not just to ensure functionality, but for manufacturability as well. It had to be reinforced to support the stresses created by side loads on the shaft. To allow molding in a simple two-part mold, the new design had to eliminate undercuts. The part was designed with relatively constant wall thickness to avoid sink, voids and warp. And it had to be drafted to facilitate ejection from the mold. But the resulting part was lighter, less expensive, maintenance free and required no assembly.

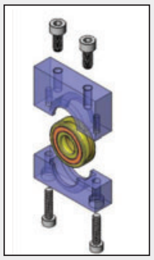

Figure 1

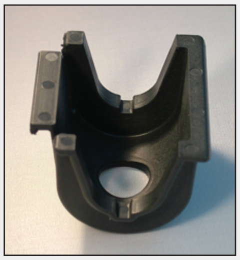

Figure 2

> The resulting part was lighter, less expensive, easy to maintain, and required no assembly.

Of course every conversion is different. In some cases, a single metal part might have to be broken into two or more for production in plastic. These could then be joined by molded-in snaps or clips, by welding, or with connectors. Plastic parts may require ribs or other reinforcements in order to withstand stresses. And they might require specific resins in order to perform their functions. For example, a part requiring metal-like strength might be made of carbon, Kevlar, or glass-filled resins.

Of course metal isn't the only material being replaced with plastic.

- **Glass** can be replaced with acrylic, which can be brittle but is low cost and has excellent optical properties or polycarbonate, which is light and impact resistant, making it ideal for applications from eyeglass lenses to bullet-proof windows
- **Rubber** has been widely replaced with thermoplastic elastomers (TPE) and thermoplastic olefins (TPO), both inexpensive, and thermoplastic polyurethanes, which are tear, abrasion, and chemical resistant
- **Metal foils** are replaced with static-dissipating plastics for packaging sensitive electrical components
- **Thermosetting** plastics can be replaced with a variety of high temperature/high stiffness thermoplastics to simplify manufacturing
- **Enamels and paints** are being replaced with thermoplastic powder-coating
- **Ceramics** are replaced with plastic; everyday examples include plastic tableware, both disposable and non-disposable

Actual food is being widely replaced with plastic display dishes in restaurants, and as many a disappointed fish can attest, living creatures, from minnows to frogs to earthworms, are now being replaced with live-looking and live-smelling plastic fishing baits.

Plastic: The Outer Limits

In describing the plastic part pictured opposite in Figures 1 & 2, we said that the molded part had replaced seven metal parts. In fact, one of those metal parts was a bearing assembly consisting of races, a cage and individual balls. So with the ball bearings gone, what reduces friction? The plastic itself.

It's a rare plastic that can take the place of an engineered metal bearing assembly, but RTP 200 AR 15 TFE 15 does the trick in this application. Offered by RTP Company and consisting of 15 percent aramid fiber for strength and abrasion resistance, 15 percent PTFE for lubricity, and 70 percent Nylon 6/6, it is a very specialized plastic. But it did its job of replacing metal admirably. Not only did it provide a low friction bearing surface for the printer's metal shaft, but it proved so durable that, over time, the steel shaft wore before the plastic bearing did.

This is just one example of the extremes to which plastic resins have been engineered. Other examples include:

- 60% long glass fiber nylon with tensile strength of 33,000 psi and a heat deflection temperature (at 264psi stress) of 460°F, making it suitable in applications requiring very high strength and heat resistance.
- Ryton R4 PPS (polyphenylene sulfide), while not quite as high in tensile strength as the glass reinforced nylon has even higher heat temperature deflection (500°F) and is resistant to automotive/ diesel fluids and combustion byproducts. This makes it suitable for long-term use in the grueling conditions produced under the hoods of diesel vehicles.
- RADEL R-5000 PSU provides hydrolytic stability, high deflection temperatures and outstanding resistance to environmental stress cracking. Its Izod impact resistance is a very high 13.0 ft-lb/sq. in. It is popular for medical applications and its heat stability and good electrical properties suit it for electrical and electronic applications in which high impact resistance is required.
- Zytel ST nylon has an extraordinarily high impact resistance of 44.3 ft-lb/sq. in.; no surprise considering that the "ST" stands for "super tough." That, along with excellent flow characteristics, allows the production of parts with thinner walls, longer rails, and stronger knit lines. The resin is used in sporting goods, safety equipment, power tools, and appliances.

Other resins boast different sorts of unique characteristics.

- Polyetheretherketone* (aka PEEK) melts at around 350°C (662°F) and is highly resistant to thermal degradation. The material is also resistant to both organic and aqueous environments, and is used in bearings, piston parts, pumps, compressor plate valves, and cable insulation applications. It is one of the few plastics compatible with ultra-high vacuum applications.
- Ultem*, one of the strongest resins available, has excellent chemical resistance and low shrink so it can make low warp, accurate parts. It is used in many applications including medical, chemical resistant, and power supplies.
- Glow-in-the-dark blends of PP, PE, AS, ABS, PC, PS, PET, and other plastics are available for a variety of applications from toys to latches which allow people locked into car trunks to escape.
- Scent impregnated plastic is used for fish bait, chocolate scented mousetraps, air fresheners, and more.

For additional information on these and other plastics, both common and exotic, visit:

IDES, the plastic web
with over 70,000 data sheets
www.ides.com

RTP Company
a leader in specialty compounding
www.rtpcompany.com

*Protomold's rapid injection molding process is not compatible with these resins, but they can be machined just fine by First Cut Prototype.

What's New

WHAT'S NEW AT PROTOMOLD?

Bigger Parts

Bigger presses mean bigger parts, and we've set up a couple of 700-ton behemoths. Now we're working to determine exactly how much larger our new size limits will be. It depends on many factors, and we will continue to push this envelope as fast and as far as we can. As we change these numbers, we'll post the information on our website and include it in our next email update. In the meantime, if you have a part in mind and want to know if we can handle it, just upload it for a free ProtoQuote® interactive quote at www.protomold.com.

Deeper Undercuts

As you probably know, we've been able, for some time, to accommodate undercuts in a design, using up to four side actions per mold. We are now tooling up for an increase in the length of cams from 1.73 inches of travel to 2.9 inches of travel. That means deeper undercuts. Got a part we couldn't make before? Give us another try.

WHAT'S NEW AT FIRST CUT PROTOTYPE?

Faster Growth

We used to be pretty impressed with the growth rate at Protomold, but First Cut Prototype is off to an even faster start than Protomold was. After just 14 months in business, FCP is already growing at three times the rate Protomold grew during the corresponding period in its history! To keep up with demand, we are adding another eight CNC milling machines at our Maple Plain, MN, facility.

But we aren't just making more parts, we're machining them in more kinds of material. Over the course of the year, we have added Ultem, GF Ultem, PVC, CPVC and PEEK to our list of stocked materials. (For an up to date list, see our website at www.firstcut.com/MaterialSelection.aspx.) This provides an option for prototypes in materials that Protomold is not able to work in. While First Cut's maximum part size is still limited to 10 inches x 7 inches x 3 inches deep, not all materials are available in thicknesses to support a part of this depth. We have found sources for thicker stock on several materials like translucent polycarbonate, clear polycarbonate and 30% glass filled nylon. Your FirstQuote™ interactive quote will present the available material choices for your part(s).

Meanwhile, in Europe...

First Cut Prototype Europe, located in Telford, England, is now operational and already shipping parts to customers. The facility has ten CNC milling machines in operation and 16,000 square feet in which to expand.

Upcoming Tradeshow

Both Protomold and First Cut Prototype will be at the Pacific Design & Manufacturing Show at the Anaheim Convention Center on January 29-31.

First Cut Prototype will be in booth #3712

Protomold will be in booth #3714

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