How High Performance Liquid Crystal Polymers Cut the Cost of Precision Medical Parts

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With liquid crystal polymers (LCPs), the medical device designer can improve part economics as well as performance and processing compared with metals and other plastic materials. LCPs eliminate costly machining, fill thinner walls, shorten molding cycles, and provide higher yields of stronger, more precise parts. By virtue of their design and processing advantages, LCPs can indeed justify raw material cost which may be higher than some other resins. How can medical designers capitalize on the design flexibility and cost savings possible with LCPs? To start, a fundamental concept must be understood: The cost-effectiveness of a resin lies in the finished cost per useable part, not in the price per pound of plastic.

Raw Material Cost Can Be Deceiving
Cost per part is a function of the raw material chosen, part design and all its processing requirements. One of these elements alone does not tell the whole story. In one medical device, for example, the raw material cost was roughly $0.07/part when molded in modified polyphenylene oxide (PPO) at $4/lb. When molded in Vectra® LCP, the raw material cost was around 37 cents per part. But LCP, the higher-priced raw material, led to processing advantages that ultimately generated a significant cost saving per useable part. The Vectra® LCP processed much faster than PPO, so lower machine cost, because of throughput, recaptures some of the difference in material costs. However, in this case the molding accuracy and creep resistance of LCP generated the major cost savings.

The PPO parts required an annealing operation with lots of manual handling and temperature adjustments. The time and labor of this extra step added 58 cents to the manufacturing cost of each piece and yielded useable parts just 85% of the time. With proper design, the LCP parts were ready to use as-molded and needed no annealing. When one looked at the entire picture, the finished-part cost of Vectra® LCP was at least 30 cents per part lower, even though it had a higher price per pound.

Savings In Cycles
To understand the cost advantages possible with LCPs, one must consider the molding behavior of polymers. Amorphous and semi-crystalline polymers both have random microstructures when they melt. Amorphous polymers retain their random orientation when they cool. Parts molded in amorphous resins consequently have good impact strength but relatively poor stiffness. Increasing the molecular weight of amorphous polymers to improve their load-bearing strength increases their melt viscosity, and makes them more difficult to mold in thin-wall sections.

Semi-crystalline polymers also have a random microstructure when melted. However, as they cool, they form highly ordered crystalline regions surrounded by an amorphous matrix. The organized structure improves load-bearing strength and chemical resistance, but reduces impact strength. Compared to amorphous resins, semi-crystalline polymers are generally easier to mold because they have much lower melting points, lower melt viscosity, promoting filling thin-wall sections.
Compared to semi-crystalline resins, liquid crystal polymers offer molders better processability, and designers higher mechanical strength. In the melt stage, the rigid rods of LCP molecules remain ordered like uncooked spaghetti. The rigid rod morphology of LCPs also limits tangling of the molecular chains. They slide over one another under shear, yielding a very low melt viscosity, making it easy to fill thin walls and fine details. The resin consequently needs little pressure to make it flow. LCPs are highly ordered in the melt phase, so they require little or no time to crystallize as they cool to their solid phase. Furthermore, the plastic in the mold is stiff when still hot and can be ejected quickly.

Low heat of fusion, negligible time to crystallize, and high stiffness when hot may result in LCP molding cycles half as long as with ordinary thermoplastics. The PPO part in the earlier example had a cycle time of 29 seconds. The LCP alternative cycled in just 16 seconds. Faster cycles save molding machine time, labor charges and tooling cost per part.

**Thin Wall Economy**
The melt viscosity of LCPs is far lower than that of most competitive materials. At 1,000 reciprocal seconds, Vectra® LCP A130 has a melt viscosity of 600 poise. By comparison, a medical grade of polycarbonate has a viscosity of 2,900 poise. A medical grade of polysulfone has a viscosity of 9,000 poise. All resins were measured at their normal melt temperatures.

The lower melt viscosity of LCPs translates into higher flow in thin wall sections. In a tool with a ½ in. wide cavity, Vectra® A130 LCP flows up to 12 in. through a 0.031 in. thickness. It flows over 50 in. through 0.125 in. thickness. Many competitive materials flow about 60% of those lengths in such thin sections. Plus, some resins simply cannot fill a 0.031 in. thick cavity at all.

With Vectra® LCPs, a part 13.5 in. long can be molded with a minimum wall section of 0.035 in., excluding draft. To fill that length, most competitive materials require wall thickness at least 0.080 in. thick. With 60% thinner walls, LCP can naturally cut the quantity of resin consumed and the material cost per part.

More important than simply filling thin sections, Vectra® LCP has the mechanical properties to make thin-walled parts strong and stiff. Unlike most resins, LCPs get stiffer as they get thinner. As LCP fills a mold, surface molecules align with the flow and form a skin comprising about 15 to 30% of the part thickness. This reinforcing layer gives the part high flexural and tensile strength, and modulus. The thinner the part section, the greater the proportion of highly oriented skin, resulting in improved mechanical performance in the direction of flow.

To improve the mechanical performance of most plastic parts, designers commonly increase wall thickness. Thicker walls use more resin, and make a bulkier part. With LCPs, higher mechanical performance in thinner walls can reduce material cost. If specific stiffness is calculated as flexural modulus divided by resin cost adjusted for density, LCPs outperform competitive plastics. In terms of “psi per penny,” liquid crystal polymer performs about twice as well as less costly amorphous materials. LCPs also reinforce themselves by forming reinforcing fibrils. Thus, they compare favorably in strength and stiffness with even more costly high performance carbon fiber fillednylons and long-fiber filled composites.

For example, a medical component molded of 40% carbon fiber filled nylon, was more expensive per pound than Vectra® A130 LCP just for the resin. Using liquid crystal polymer in the same part would save about three cents per part before thinning wall sections.
**Process Savings**
The liquid crystal polymer also cycles faster than most competitive materials. Cycle times with carbon-filled nylon are about 26 seconds. LCP can reduce cycle time from 16 to 22 seconds, saving 6 to 14 cents a part. Carbon fiber is also very abrasive and requires frequent tool repairs. The direct cost of such maintenance is compounded by the cost of downtime and scheduling inefficiencies.

With its low viscosity, LCP typically causes far less mold wear than similarly filled materials. Reduced maintenance costs and more favorable tool amortization can save almost 9 cents a part. For one major medical manufacturer, switching from carbon-filled nylon to LCP generates total savings of roughly 14 cents a part or $34,000 a year.

**High Yields As Molded**
Accurate, repeatable parts have their own payoffs. With amorphous and semi-crystalline polymers, the overall dimensions of molded parts include volume occupied by random coiled molecules. As the plastic cools, the polymer molecules contract as the motion decreases and crystallization reduces the gross resin volume significantly.

By comparison, the rigid polymer rods of LCPs always remain aligned in the flow direction. Gross part dimensions change little with processing conditions. LCPs commonly shrink less than 0.001 in. per inch of part length in the flow direction. Shrinkage is also relatively insensitive to processing condition, so LCPs hold extremely tight tolerances in the direction of flow.

Injection molding of LCPs is very repeatable and variation from part to part is extremely small. Precise parts minimize assembly problems and rejects. Extremely competitive electronic connector manufacturers report that Vectra® LCP allows them to achieve yields of acceptable quality parts of 98% or better. Consistent, precise part dimensions eliminate costly secondary operations such as the machining commonly required with metal castings. LCPs also produce little or no flash, so they need no expensive deflashing steps common to some other plastics.

The maker of one surgical instrument specified glass-filled Vectra® LCP for a two-piece body. The body halves had to be molded to tolerances of ±0.005 in. over 6 in. without flash. Strict cost goals and finish requirements would tolerate no trimming or any operation which could expose glass fibers. The slightly textured housing material also had to accept custom colors. Compared to competitive resins, Liquid Crystal Polymer provided the right combination of dimensional stability, flash-free molding, and colorability need to cut manufacturing costs.

**Metal Replacement Savings**
Liquid crystal polymers can generate dramatic savings in metal replacement applications. They can replicate complex geometries without costly machining, and can consolidate functions of several parts. The consolidation of multiple parts eliminates the expense of separate tools with associated tooling time. Part consolidation also reduces assembly steps and losses in yield at each operation.

Unlike metals, LCPs enable molders to achieve very precise dimensions and tolerances without expensive machining. The alignment of rigid rod molecules results in a very low coefficient of
thermal expansion (CTE) minimizing shrinkage as parts cool from the melt. Low CTE also minimizes expansion when parts are sterilized or soldered. In most metal forming processes, tight tolerances on critical features require some machining. Even with computer controlled machining, the overall process remains operator intensive and therefore more expensive and less efficient than injection molding. In plastics, the designer can also color code parts to simplify assembly and enhance aesthetics without secondary finishing operations.

In one dramatic example of the savings possible with plastics, surgical manufacturer Pilling-Weck used Vectra® LCP in the functional half of a ligating clip cartridge. The mechanically demanding part requires extremely precise dimensions. Suppliers quote a rough cost estimate for the machined metal component at $50 to $60 apiece. By dramatic comparison, the injection molded part costs the manufacturer just 84 cents.

In another example, designers of the Medi-Jector® needle-less syringe made the device lighter, easier to use, and less expensive to manufacture with Vectra® LCP. The latest generation of the Medi-Jector has critical load-carrying plastic parts 50% less costly than the metal components they replaced. The switch from greased metal parts to self-lubricating plastics components made the precision spring-loaded device easier for users to wind up before each injection. It also opened new application opportunities for the syringe maker to modify the device for different user populations, without the machining costs associated with metals.

**Estimate The Difference**
When commercial developers of a surgical skin-stretcher sought to convert the stainless steel prototype into an affordable, disposable instrument, they chose LCP. Most surgical instruments have stainless steel parts fabricated by cutting, welding, machining, and other processes. Each geometry requires a different combination of manufacturing processes and unique costs. Although the attendant costs are difficult to generalize, most stainless steel fabrication processes are more expensive than those associated with die casting. We can estimate die casting costs to provide some comparisons between metals and liquid crystal polymers.

The die casting industry publishes generic costs for forming metals. Assuming a part molded in liquid crystal polymer costs 1.0X, molding costs usually average less than half the material cost - in this case 0.5X. Total cost of the plastic part can therefore be estimated at roughly 1.5X.

To draw some rough comparisons between molded plastics and machined metal parts, let us further assume a metal part having similar raw material cost. Most stainless steels cost roughly one quarter as much as Vectra® LCP but are four to five times as dense. When price is adjusted for density, material costs are actually very similar. Diecasters estimate the cost of forming is roughly 1.35 times the raw material cost including expense of the process, tool wear, and associated factors. Finishing the part, including trimming, deflashing, and drilling the casting, costs another 1.4 times raw material cost. The final part cost could therefore total 3.75 times the basic material cost -- more than double that of molded Vectra® LCP component.

Using the same assumptions, consider a part designed in metal. Even with a metal part thin enough to halve material costs, the finished piece still embodies forming and finishing costs 2.75 times material costs. With these assumptions, the metal part with all its fabricating costs would still cost more than the LCP part, even if the metal were free.
**Summing Up**

For the success of any project, it is important to focus on the final cost of the part. When the designer exploits the inherent strengths of LCP, the plastic enhances productivity and improves part economics.

Compared to amorphous resins, liquid crystal polymer provides extremely fast molding cycles and therefore low production costs. The thin-wall performance of the material generates significant material savings. The unique rod-like microstructure of the material yields precise, reproducible dimensions which improve production economics and assembly reliability.

Relative to metals, Vectra® LCP enables the designer to consolidate parts and eliminate the costs of multiple tools as well as unnecessary assembly procedures. The dimensional precision of Vectra® LCP can hold tight tolerances in complex geometries without expensive machining. In short, the material enables superior productivity and economics. With LCPs, the bottom line is finished part cost.

**Figure 1**

Strong, stiff, thin-walled structures molded from Vectra® Liquid Crystal Polymer enabled Pilling-Weck to make the disposable cartridge of the reposable Hemoclip® EcoSystem™ ligating device.
Engineers at Medi-Ject exploited thin-walled strength of Vectra® Liquid Crystal Polymer to give their needle-free syringe an injector body housing and spring containment tube 75% lighter and 50% less costly than earlier metal components.
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Vectra® is not intended for use in medical or dental implants.

Products Offered by Ticona

Celcon® and Hostaform® acetal copolymer (POM)
GUR® ultra-high molecular weight polyethylene (UHMWPE)
Celax® thermoplastic polyester
Celanex® thermoplastic polyester
Impet® thermoplastic polyester
Vandar® thermoplastic polyester alloy
Riteflex® thermoplastic polyester elastomer
Vectra® liquid crystal polymer (LCP)
Celstran® long fiber reinforced thermoplastics (LFRT)
Fortron® polyphenylene sulfide (PPS)
Celanese® nylon 6/6 (PA 6/6)
Topas® cyclic olefin copolymer (COC)

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