New Structural Polymer for Metal Replacement Applications

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Abstract

Recent developments based on a novel thermoplastic Liquid Crystal Polymer (LCP) molecule and compound formulation have led to a new material which can exceed the properties of traditional plastics and demonstrate metal-like properties for structural applications. Developed with a very high modulus (>20,000MPa), tensile strength (125 MPa) and an extremely high strength-to-weight ratio, this material is isotropic and has a tailored Coefficient of Thermal Expansion (CTE) of $17x10^{-6}$/°C matching aluminum and steel. The material has balanced dimensional stability and ultra-low shrinkage (0.05%) with high temperature stability up to 420°C. These metal-like properties have been identified as a metal replacement material for structural applications in a variety of applications and markets.

Introduction

In the structural, building, medical, consumer product, and automotive industries the need for polymeric materials which are lightweight and provide metal-like properties is a long sought after goal. Eliminating the cast and machined metal processes reduces weight and dramatically lowers costs.

The trends in many of the above mentioned markets have seen a convergence of both miniaturization and enhanced mechanical properties. This has caused components which have been traditionally injection molded to be substituted for a metallic based solution. A polymeric solution that satisfy the consumer by meeting the mechanical specifications, durability, and toughness while maintaining strict thin wall design requirements and competitive molders cost. This would allow for injection molding to recapture solutions that require miniaturization, enhanced mechanical properties, and thermal properties. On larger products strength to weight ratio and heat deflection temperature are key advantages.

Structural plastics for metal replacement have traditionally utilized formulation techniques of incorporating additives such as glass and carbon fibers. Examples of these formulations include glass filled nylons and polyamides which provide sufficient stiffness and tensile strength but also include inherent weaknesses such as anisotropy, high moisture absorption and very high CTE. There are higher performance materials such as PPS and PPSU that are extremely difficult to process and all of these materials provide manufacturing challenges, such as high viscosity and mold wear.

Material Technology and Properties

Isotropic and CTE Matching Metal

A class of new materials introduced by QLP Inc. is based on LCP derivatives, innovative nano scale filler technology and compound formulation. The isotropy of this novel thermoplastic LCP is a critical attribute that allows balanced properties across all dimensions of a molded part. It has a tailored CTE of $<20x10^{-6}$/°C in both the mold and cross-flow direction. Figures 1 and 2 show measured CTE in the flow and cross-flow directions respectively:

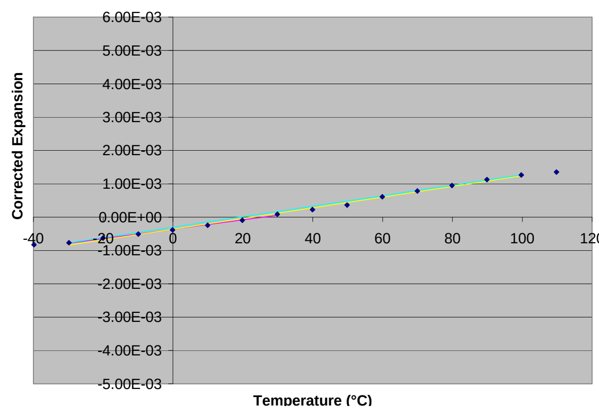

Figure 1: CTE of Novel Thermoplastic LCP in Flow Direction, $17x10^{-6}$/°C

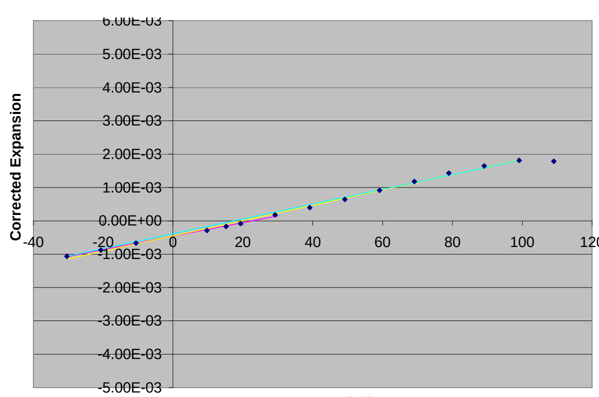

Figure 2: CTE of Novel Thermoplastic LCP in Cross Flow Directions, $15x10^{-6}$/°C

A balanced CTE addresses a fundamental problem with current plastics which are anisotropic and possess significantly different expansion and shrinkage in the x, y, and z axis. For example, 40% glass filled nylon will have a CTE of $50x10E^{-6}$/C in the x-direction (molded direction) and $120x10E^{-6}$/C in the y-direction (transverse mold direction). This leads to poor dimensional stability, high shrinkage and warpage in real life applications. Assembly methods become difficult due to part misalignment, gaps at plastic-metal interfaces occur and significant mold rework is necessary to compensate for material shrinkage.

With a tailored CTE matching aluminum and steel, the behavior of the novel LCP is very close to metal and exhibits outstanding dimensional stability and ultra-low shrinkage. Figure 3 compares the CTE of several materials, both plastic and metals, to the novel thermoplastic LCP. Note the balanced CTE in both the molded direction (X) and transverse (Y) direction as well as the matched CTE to steel, Al and Mg.

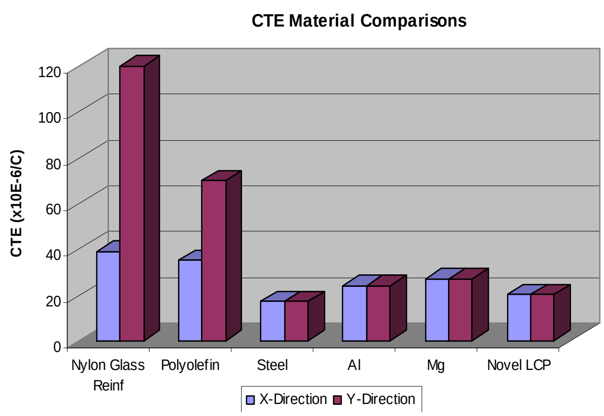

Figure 3: CTE Material Comparison

Figure 4 below graphically shows the shrinkage compared to glass filled nylon and polyolefins. This material is measured with less than 0.05% shrinkage and low moisture (0.08%) which allows high dimensional stability and low warpage.

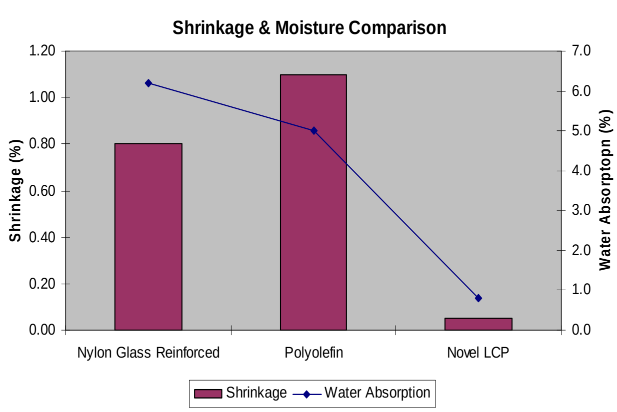

Figure 4: Shrinkage and Moisture Study

Strength to Weight Ratio

Table I lists the physical properties. The low density and structural strength leads to a high strength to weight ratio that exceeds metals. This is illustrated in Figure 5.

Table I: Structural Properties

	Unit	Novel thermoplastic LCP
CLE - isotropic		
X	10^{-6} /°C	13.5
Y	10^{-6} /°C	14.2
Tensile Strength	MPa	125
Flexural Modulus	MPa	13,620
Tensile Modulus	MPa	14,177
Young's Strain, Yield*	%	1.73
Density	g/cc	1.75
Notched Charpy	kJ/m2	2.7
Water Uptake (1hr at 100°C water)	%	0.08
Shrinkage	%	<0.05
Heat Deflection	°C	320

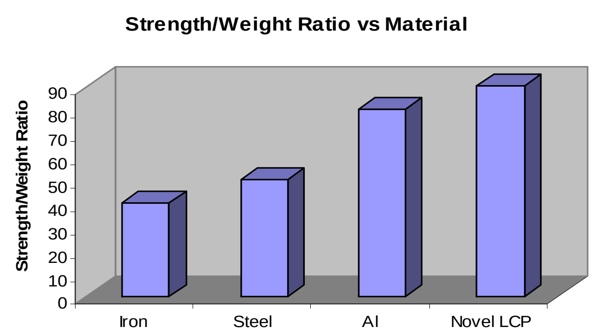

Figure 5: Strength/Weight Ratio Comparison

Applications

Moldflow™ simulations and real life applications demonstrate the advantages of the novel LCP material properties described above. Figure 6 is Moldflow™ study of a structural bracket using a 60% glass filled nylon.

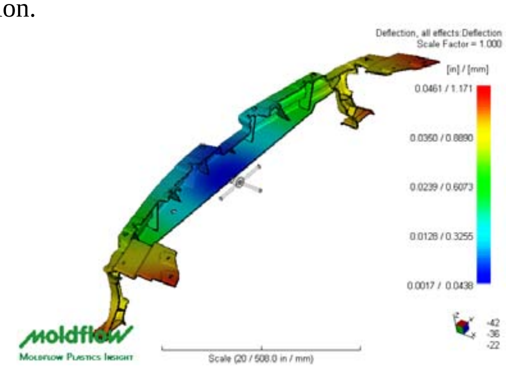

Figure 6: Mold flow Analysis of Glass Filled Nylon

Compare this to Figure 7, a mold flow study of the same part but using the novel thermoplastic LCP.

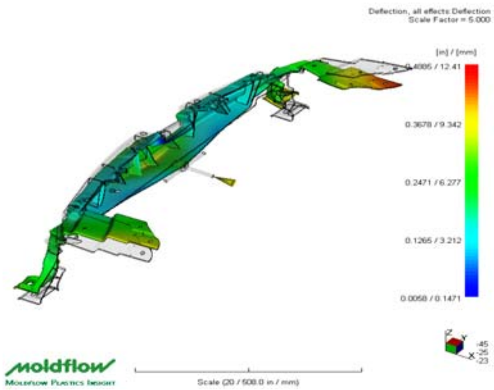

Figure 7: Mold Flow Analysis of the Novel Thermoplastic LCP

The material's stiffness and dimensional stability enables a thinner wall of 0.090" compared to the glass filled nylon of 0.135", allowing less material usage. A key performance advantage is realized in the warpage. The novel thermoplastic LCP has minimal warp of only 0.044" whereas the glass filled nylon warps 10 times at 0.489" This is a significant benefit for assembly alignment and minimizing gaps when joined at metal interfaces. Table II outlines the comparisons.

Table II: Mold Flow Comparisons of Structural Bracket

	60% Glass Filled Nylon	Novel LCP
Wall Thickness (inch)	0.135"	0.090"
Warpage (inch)	0.489"	0.044"
Injection Pressure (psi)	18,728	8,687
Cycle time (sec)	20	10

These beneficial results lead to several applications now being evaluated for metal replacement. This includes structural, building, medical, automotive and electronic applications where dimensional stability and structural strength is critical.

Manufacturing & Processing

This material is 100% crystalline with a very low heat of fusion. It processes at an extremely low viscosity. Figure 8 shows the viscosity curve. This allows extremely fast cycle times, lower injection pressures and complex geometries. Table II shows the cycle time and injection pressures are reduced by 50% and 54% respectively when comparing glass filled nylon to the novel LCP. Total cost of manufacturing is lowered by increasing production yields and utilizing low press clam force.

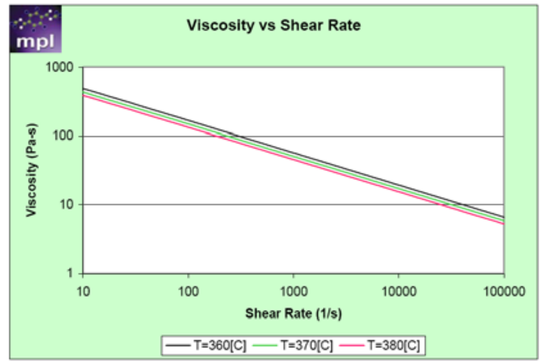

Figure 8: Viscosity vs. Shear of Novel Thermoplastic LCP

Polymers with high glass content (20% and above) are considered extremely abrasive materials. When using these materials, total manufacturing costs increase on a number of different levels. In the tool design phase, areas of wear need to be identified and a more robust tool design is required to mitigate risk. For example, choosing an abrasive polymer for a product limits the tool steel selection, gate location, gate size, and runner technology. Designing in tool components that can easily be replaced once wear reaches a critical level may decrease costs overall, however, design time and changes may also increase.

Selecting tool steel that has a Rockwell hardness of 60 or above may also be necessary. When comparing to the Rockwell hardness of traditional tool steel, material costs will increase. If harder material steel is used, frequency of replacing cutters and longer set up time will increase fabrication costs. It is also possible a wear resistant coating would need to be applied to the steel after machining. These incremental cost increases should be considered when discussing the use of an abrasive polymer. In approximation, the industry averages indicate a tool designed to run glass filled polymers for 2 million cycles would require replacement parts for wear twice over the life of the tool. If a similar tool was designed to run non-glass filled polymers, than replacement parts for wear may not be required. Additionally, the low shrinkage and dimensional stability of the material minimizes mold re-work costs for newly designed parts.

Figure 9 shows a Pressure-Volume-Temperature curve (PVT) comparing an industry standard 30% glass filled nylon (upper 4 curves) to the novel thermoplastic LCP (lower 4 curves). The X axis is temperature ranging from room temperature through melting temperature. The Y axis represents specific volume. Each line represents a different pressure. Note that the novel LCP has a much tighter distribution compared to the 30% glass filled nylon. This translates to minimal volumetric change, lower expansion and dimensional stability over a wide temperature range and varying pressures.

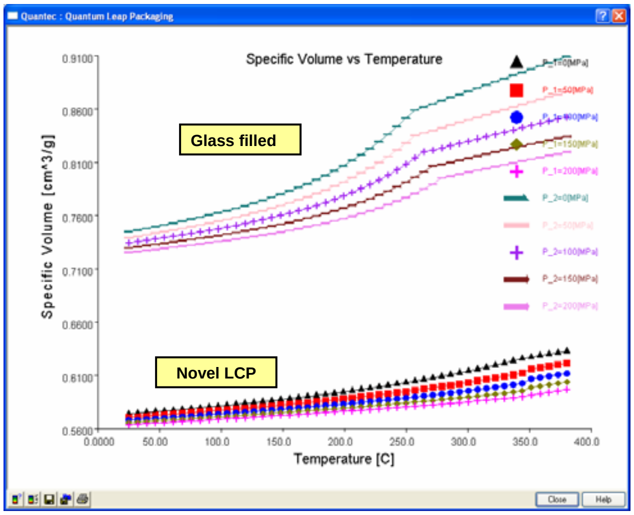

Figure 9: Specific Volume vs Temperature

Glass filled polymers can require an increase in injection pressures. A thin walled component with a nominal cross section of 0.037", a flow length of 3.25" and direct valve gate was used in an injection pressure analysis. The geometry was molded with the novel LCP, PC/ABS and a 50% glass filled Nylon. The resulting peak injection pressures and fill times can be seen in Figure 10. The novel LCP had a 47% lower injection pressure while maintaining at least half the fill speed then the glass filled nylon, which was using 100% of machine capacity. The novel LCP had a 29% lower injection pressure then the PC/ABS material.

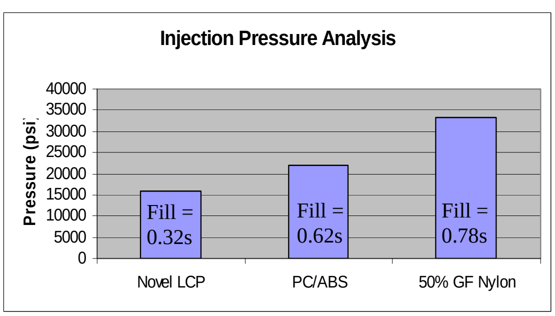

Figure 10: Injection Pressure vs. Material

Impact Analysis Case Study

For many applications, impact properties are essential. It is important to understand these properties during the product design and material selection phase of development to ensure the product meets customer specifications. It is beneficial to analyze impact properties using standard testing protocols and test plaques as well as application case studies. Design features such as welds, corners, and thickness transitions can have a drastic effect on impact performance.

Handheld electronic devices such as mobile telephones require strict standards on impact performance. These standards are typically unique dependent on the geometry and targeted quality of the product. A cellular telephone housing was molded out of the novel LCP and tested using a standard falling dart test (ASTM D1709). The experiment was set up to ensure the falling dart impacted the same area of the part each test. A four pound weight dart and a 0.625" rounded nose punch were utilized. Multiple materials were analyzed to determine the dart height that creates product failure. Two failure notes were made, initial cracking and a break through the cross section of the part. The nominal cross section of the mobile housing is 0.037". The results from the analysis can be seen below in Table III. The results showed that one of the novel grades of LCP performed identical to an industry accepted grade of glass filled nylon for cell phone housings.

Table III: Mobile Phone Impact Results

	Initial Crack	Broke Through
Novel LCP A	4"	8"
Novel LCP B	1"	3"
Novel LCP C	1"	3"
50% Glass Filled Nylon	4"	8"

Novel LCP Grade C was engineered with the highest stiffness and strength. It was not designed to perform well for impact applications. Novel LCP Grade A, was specifically developed for impact, and the data in Table III shows that the product demonstrates the same performance as engineered and impact modified (rubber) glass filled nylon. The Charpy data for the materials is reported in Table IV, which is consistent with the results in table III.

Table IV. Charpy Impact Strength

Material	Notched Charpy J/m
Novel LCP A	24
Novel LCP B	50
Novel LCP C	80-104
50% Glass Filled Nylon	70-100

Paintability

As previously mentioned, applications for the consumer, medical, and electronics market are requiring enhanced mechanical properties for products while at the same time achieving a level of brand differentiation among competitive products. Often times, post molding decorative technologies are necessary to enhance the look and feel of the product. In order to achieve cost effective (high through put and yield), many post molding decoration processes require a high level of adhesion for inks and coatings to the molded plastic component.

Glass filled polymers can be difficult to decorate. If the product is not processed and designed correctly, glass content can migrate to the surface of the part and/or a high level of internal stresses will cause surface tension. Both these sceneries are not ideal for ink and coating adhesion. Costly engineering time is required to properly design and adjust processing parameters to optimize surface characteristics for post molding decoration. Pretreatment operations such as corona, plasma, or UV exposures are used to further improve surface characteristics beyond design and process optimization. These processes, although necessary add costs to capital expenditure and manufacturing.

A DOE was executed to better understand the benefits of the novel thermoplastic LCP when comparing to a 50% filled polymers. A thin walled, large surface area geometry part was chosen. After molding, a portion of these components were surface treated with plasma. Untreated components were painted along side of treated components. After decoration, components were tested using the ASTM 3359 standard for cross cut adhesion. The results can be seen below in figure 11. After pretreatment the Novel LCP preformed equivalent to other industry standard materials.

The Novel LCP decorated samples were also tested after temperature shock exposure. The samples were cycled 24 times at temperatures of -40°F and 176°F. They remained at stable temperature for 30 minutes. After the exposure, there was no decrease in adhesion performance.

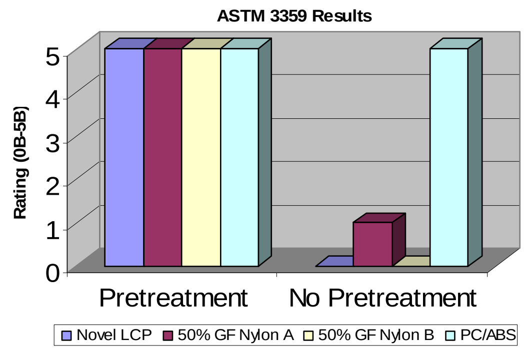

Figure 11: Paint Adhesion vs. Material

Conclusion

A new polymer based on a novel thermoplastic LCP molecule and innovative compound formulation provides a structure with a strength-to-weight ratio higher than metals. Key material properties such as isotropy, tailored CTE to match metal, high dimensional stability, and ultra-low shrinkage are properties that serve as a metal replacement alternative for structural applications. Additionally, the unique LCP's filler technology and viscosity properties lower total cost of manufacturing due to reduced mold wear, lower tool maintenance/rework costs and faster cycle times.

This novel LCP material is in production and evaluation in several applications such as building, structural, automotive, medical and consumer products.

Key Words

Thermoplastic, Liquid Crystal Polymer (LCP), isotropic, Coefficient of Thermal Expansion (CTE), dimensional stability, shrinkage, injection molding, strength to weight rations