CASE STUDY:

Less is More with Ultra High-Performance Thermoplastics for Space Flight Components

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ADVANCED POLYMERS COMBINE LESS WEIGHT WITH HIGHER PERFORMANCE IN SPACE FLIGHT VEHICLE TUBE MANAGEMENT HARDWARE

Aerospace design engineers place a high priority on reducing equipment weight. Every component is evaluated, including the numerous small parts of systems where saving a few grams can add up to a significant total weight reduction. At the same time, it is essential that reliability and functional integrity are never compromised.

Consequently, when a clear opportunity arises to cut weight and gain an improvement in the performance, ease of installation and dependability of a component, it becomes a particularly attractive option.

Drake Plastics' expertise in high-performance thermoplastics, aerospace industry applications and advanced polymer processing capabilities helped its customer's engineers capitalize on just such an opportunity.

HIGHER PERFORMANCE AND LIGHTER WEIGHT TUBE MOUNTS AND SUPPORTS

Structural supports for tubing systems in space flight vehicles serve as a case in point for "less is more." When engineers working on the design of these components contacted Drake's technical support team for material options, their joint evaluation led to the specification of Torlon 7130 PAI. The 7130 grade is a high strength 30% carbon fiber reinforced formulation of polyamide-imide thermoplastic from Syensqo* (formerly Solvay) who supplies the resin globally.

Torlon 7130 offers excellent 'material efficiency.' Its Specific Strength, *(Table 1)* or the ratio between tensile strength and density, compares very favorably to common aerospace metals. The ultra high-performance thermoplastic also maintains its toughness and strength from cryogenic temperatures to over 200°C. These performance attributes and the ability to injection mold complex parts that could be easily installed by bonding made Torlon 7130 the clear choice.

Table 1: Specific Strength of Torlon 7130 vs. Aerospace Metals

	Torlon 7130 PAI	2011 Al	301 SS	Titanium
Specific Strength, 10^5 J/kg	1.4	1.3	0.8	8.1

*Data Source: Syensqo (formerly Solvay)**

With the material specification in place, the collaborative project between Drake and the customer led to the production of a series of components with less weight and higher performance than would have been possible with metals and other material candidates. Additionally, the efficiencies of injection molding yielded components at a fraction of the cost of the same parts had they been machined from metals or other polymers.

Tube supports Injection Molded from Torlon 7130 PAI

THERMAL ISOLATION AT LOW AND HIGH TEMPERATURES

Thermal isolation is an important attribute for components that interface with tubing systems. The material from which the components are made must be able to prevent thermal shocks to the fluids and gases in the system itself. This is an area where Torlon 7130 with its thermal conductivity of 0.52 W/m/K per ASTM C177 clearly excels over metals *(Table 2)*.

Table 2: Thermal Conductivity – Torlon 7130 vs. Metals

	Torlon 7130 PAI	Stainless Steel	Aluminium Alloy
Thermal Conductivity (w/m – K)	0.52	16.3	150

*Data Source: Syensqo (formerly Solvay)**

MECHANICAL PERFORMANCE AND DIMENSIONAL STABILITY AT TEMPERATURE EXTREMES

Tube supports have several performance requirements that made Torlon 7130 the preferred candidate over other polymers and metals. Essential factors were the material's structural rigidity, its dimensional stability over severe and sudden temperature changes, and its toughness at cryogenic conditions.

While Torlon PAI offers inherently high strength, the 30% carbon-fiber reinforcement in Torlon 7130 significantly boosts its structural properties. Its flexural modulus of 19,900 MPa at 23°C measures well above that of glass-reinforced Torlon PAI, PI (polyimide) and fiber-reinforced PTFE. It also outperforms PEEK formulated with the same carbon fiber content. Most notably, Torlon 7130 retains an impressive 15,700 MPa at 232°C, well beyond the glass-transition temperature limit of PEEK and PEI (polyetherimide) polymer grades. *(Table 3)*.

Table 3: Mechanical & Thermal Properties, Production Factors

	Carbon Fiber Reinforced/Modified				Glass Fiber Reinforced			
	Torlon 7130	PEEK CF30	PCTFE 25% CF	Vespel SP-21	Torlon 7130	PEEK GF30	Ultem 2300	PCTFE 25% GF
	30% Carbon Fiber		25% Carbon Fiber	Graphite	30% Glass Fiber			25% Glass Fiber
Properties[1]								
Flexural Modulus MPa @ 23°C	19,900	17,500	1,102	3,792	11,700	10,300	9,000	1,310
Flexural Modulus MPa @ Temperature	15,700 *@ 232°C*	N/A *(Tg = 150)*	N/A *(Tg = 150)*	2,551 *@ 260°C*	9,860 *@ 232°C*	N/A *(Tg = 150)*	8,000 *@ 217°C*	N/A *(Tg = 30°C)*
Tensile Strength MPa @ 23°C	221	201	13	65.5	221	158	158	15
Compressive Strength MPa @ 23°C	254	173	12	133	264	169	221	7
Glass Transition Temp. (Tg) °C	280	150	123-134	None[2]	280	150	218	110-130[3]
Parts Production								
Injection Molding	✓	✓			✓	✓	✓	
Compression/Isostatic Molding			✓	✓				✓
Shapes Machining	✓	✓	✓	✓	✓	✓	✓	✓

[1] Property values of standards commercially available grades
[2] No observable Tg (softening point) below decomposition temperature of over 400°C
[3] Estimated range. PTFE softening point varies with degree of crystallinity

Another factor related to Torlon 7130 PAI's structural advantages for the application is its resistance to creep or distortion from high physical loads over extended periods. This translates into components that perform dependably at the elevated and cryogenic temperatures to which various tube systems are exposed in the spacecraft's operating environment.

During space flight, components of the internal operating systems must also resist fatigue failure from extreme vibrational stresses from multiple launches and other factors. Also, they must maintain the toughness required to preclude cracking under physical loads at cryogenic temperatures that embrittle many materials. As is the case with all Torlon grades, the 30% carbon fiber reinforced 7130 formulation retains the toughness and impact resistance required to perform reliably at low temperature extremes.

In addition, Torlon 7130's coefficient of linear thermal expansion measures 9.0E-6 cm/cm/°C, closely matching that of advanced aerospace composites and even steel. This translates to the dimensional stability needed over wide temperature ranges during space flight to avoid stressing the epoxy bonds that mount the components in place.

COST-EFFECTIVE PARTS PRODUCTION A KEY FACTOR

Parts production methods for the different materials are also compared in Table 3. Given the complex design of the tube support, injection molding the finished components in a single operation provided the best production economics. While machining can achieve the required complexity, material loss with the complex design would have had a significant cost impact.

PI and PFTE parts are made by compression or isostatic molding, which only permits two-dimensional features. Post-machining is required to achieve complex designs. Torlon PAI, PEEK and Ultem PEI, however, are all melt-processable thermoplastics that Drake injection molds into complex part configurations routinely. Of the injection-moldable material candidates, Torlon 7130 was specified based on its superior performance.

AEROSPACE INDUSTRY FLAMMABILITY RATINGS ESSENTIAL

Flammability and smoke generation of thermoplastics and other non-metallics are also essential factors in choosing material candidates for aerospace equipment components. Ratings based on testing done by major certified agencies and laboratories worldwide are required to validate a thermoplastic formulation's suitability for each application. The FAA's flammability, smoke density and toxic gas emission requirements are especially rigorous for components of commercial aircraft.

Torlon 7130 has a consistent record of surpassing the FAA's certification requirements for these demanding aerospace applications, and is specified for numerous injection molded parts and components machined from semi-finished shapes. Torlon PAI has also been qualified to meet NASA's Spacecraft materials requirement NHB8060.1 which includes "Flammability, Odor, and Offgassing Requirements." Additionally, all Torlon grades carry Underwriter Laboratories' UL 94 V-0 flammability rating.

POST-CURING BOOSTS TORLON PAI PERFORMANCE

Drake Plastics post-cures all injection molded parts and extruded semi-finished shapes it produces from Torlon PAI. This necessary processing step improves properties of the material in several key areas.

For example, on thermal performance, Drake's post-curing cycles achieve a typical core Tg value (glass-transition temperature) of 285°C/545°F (midpoint). This is the highest Tg of any melt-processable thermoplastic. The post-cure methodology also maximizes key property values related to the material's strength, toughness, wear resistance, and chemical resistance. The resultant boost in performance from post-curing provides customers with injection-molded components and semi-finished shapes for machined parts that have the highest levels of performance attainable with the PAI polymer.

**Syensqo is the new corporate designation for the former Solvay Specialty Polymers business.*

DRAKE

Drake Plastics Co, Ltd. is a Syensqo-approved Torlon PAI injection molder with over 25 years' experience in extruding, injection molding, post-finishing and machining ultra high-performance polymers. Its expertise includes Torlon PAI, Vespel® PI, PEEK, high-temperature PEEK, PEK and PEKK, Ryton® PPS, PAEK and Ultem PEI. The company also serves precision machining customers worldwide with an unmatched size range of semi-finished machinable shapes in multiple grades of these advanced materials.