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Maintaining Fuel Transfer in Handheld Power Equipment at Frigid Temperatures

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Low-permeation fuel tubing plays a critical role in minimizing the environmental impact of spark-ignition, power equipment such as chainsaws, trimmers, and leaf blowers. Meeting the engineering, regulatory, and cost requirements in fuel tubing often necessitates the use of advanced plastic materials. However, at low temperatures, these materials can become too rigid to maintain consistent fuel transfer. Avoiding such issues requires the use of appropriate fuel line materials and construction. In this evaluation, we assess three fuel line products: Tygon® LP-1200, Competitor A, and Competitor B for utility under low temperature conditions.

Introduction

In typical combustion-powered handheld equipment, the carburetor draws fuel through a fuel line and filter suspended inside the fuel tank. The fuel line has to meet a variety of application requirements including:

- Resistance to fuels and additives
- UV and weather resistance
- Low evaporative emissions (EPA, CARB)
- Mechanical strength for assembly, sealing, and fitting retention
- Low weight
- Reliable fuel transfer
- Kink resistance

This evaluation focuses on reliable fuel transfer. In real life applications, the fuel lines must be flexible enough to maintain consistent, air-free fuel transfer. During normal use, the equipment is oriented at different angles as needed to meet the task-at-hand. Fuel pickup lines must move, in a pendular-like motion, to the low point in the tank with the flow of the fuel in order to maintain transfer, particularly at low fuel levels. Without adequate fuel transfer, the combustion mixture can become lean; resulting in poor operation or stalling of the engine. Plastic or rubber fuel lines are well suited to meet this flexibility requirement. However, this can become a challenge at frigid temperatures if the tubing becomes too rigid. Low temperatures can also make the tubing more susceptible to mechanical shock and reduce its ability to maintain a seal or even structural integrity. Therefore, proper material selection and tubing construction are critical in order to achieve the balance of properties required for low temperature use.

Herein, a combination of evaluations is used to compare fuel line constructions for suitability under low temperature conditions. These include a static deflection test, Dynamical Mechanical Analysis (DMA), Differential Scanning Calorimetry (DSC), and a low temperature bend test (ASTM D380-12). Additionally, the application is modeled using Finite Element Analysis (FEA) to assess strain levels present in the application

Methodology

Table 1 shows the products compared in this study. These are commercially available for use in handheld power equipment.

Table 1. Fuel tubing samples.

Tube	Structure	Composition Tube (barrier)	Barrier location	Inner/Outer Diameter(in)	Color
Tygon® LP-1200	Multilayer	TPE (fluoropolymer)	I.D.	0.09/0.19	Transparent
Competitor A	Monolayer	fluoroelastomer	---	0.12/0.22	Grey/Opaque
Competitor B	Multilayer	rubber (fluoropolymer)	O.D.	0.09/0.19	Black/Opaque

There are minor differences in the dimensions (I.D. and O.D.) of the tubing products. Such differences occur because the products utilize different materials of construction and barrier technologies. The products are, however, designed to meet the same application requirements. The following evaluations were conducted:

Deflection Testing. A deflection test was conducted on samples at room (23°C) and low (-18°C) temperatures to compare their relative flexibility. Figure 1 shows the test configuration and deflection angle calculation. Appendix A contains a more detailed test procedure.

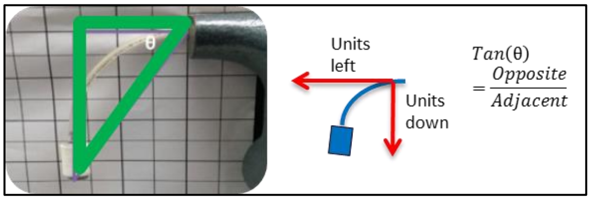

Figure 1. Left – deflection test configuration showing clamped sample (fuel line and filter) and background grid. Right – calculation of the deflection angle as a measure of sample flexibility.

Finite Element Analysis (FEA). Abaqus software was used to model a typical handheld power equipment fuel line and assess the stress-strain levels present during use. Mechanical property data for the TPE and fluoropolymer materials were utilized in the analysis.

Dynamic Mechanical Analysis (DMA). TA Instruments RSA-G2 was used to compare the tubing products' response to dynamic mechanical conditions as a function of temperature.

Differential Scanning Calorimetry (DSC). TA instruments Q2000 Calorimeter was used to determine the glass transition temperature (Tg) of the tubing materials of construction.

Low Temperature Bend (ASTM D380-12-modified). Samples of each product were cooled to -50°C for 72 h, wrapped around a 33-mm mandrel, and inspected for breakage.

Results & Discussion

Deflection Testing: A static deflection test was used for a quick comparison of tubes. Results for Tygon® LP1200 and Competitors A and B are shown in Figure 2. A higher deflection angle indicates greater flexibility.

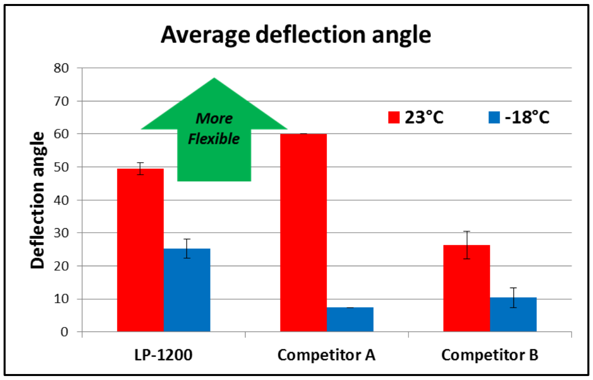

Figure 2. Deflection angle at room and low temperatures for Tygon® LP-1200 vs Competitors A and B. Higher deflection angle indicates higher flexibility.

Table 2. Tubing base-adjacent strain along the tensile-strained side of cantilevered, two-layer tube at room temperature.

Orientation of Gravity Loading (deg)*	Outer-Strain (%)	Inter-Strain (%)	Inner-Strain (%)
90	0.1%	0.1%	0.0%
60	4.5%	2.7%	1.9%
30	7.8%	4.6%	3.2%
0	9.0%	5.3%	3.6%

**90-degree orientation of loading is when the tube is just hanging, with no tilt applied.*

While Competitor A shows high flexibility at room temperature, the deflection angle decreases by more than 80% at low temperature, indicating the tube becomes very rigid. LP-1200 is flexible at room temperature and is able to maintain flexibility at low temperature, with the deflection angle decreasing by approximately 50%. Competitor B shows relatively poor flexibility at both room and low temperature. These results suggest that Tygon® LP-1200 will have superior flexibility at low temperature. Therefore, it should be better able to maintain fuel transfer under frigid conditions compared to Competitors A and B. Note that extruded tubing products typically have a natural curvature to them as a result of the manufacturing process. As detailed in Appendix A, the deflection test method takes this into consideration by measuring the deflection at two different orientations, then averaging the two values.

This is, however, a static test. Application conditions are more dynamic and the materials of construction are viscoelastic. Therefore, it is desirable to compare the tubing under more representative conditions.

FEA: To gauge appropriate conditions for dynamic testing, a typical fuel system was modeled in Abaqus as a 4"-long Tygon® LP-1200 tube (3/32" I.D.; 3/16 O.D.; 3/64" wall; TPE jacket with a fluoropolymer liner) with a 20 g filter attachment. The model was used to simulate the fuel line being held at different angles along an axis perpendicular to the tubing in order to assess strain values present during use. Figure 3 shows a strain fringe plot of a tube at a 30-degree orientation of gravity loading. The red regions show the highest magnitude of strain while the blue regions show the lowest. Table 2 shows strain values present at the base of the tube on the outer edge of the tensile strained side of the tube, at the layer interface (Inter-strain), and along the inner diameter of the tube. The results indicate that the material is subjected to relatively low (<10%) elongation even at the base of the tube the location of highest strain.

Based on the findings, DMA test conditions were derived to assess the tubes relative to one another under more dynamic mechanical and thermal conditions.

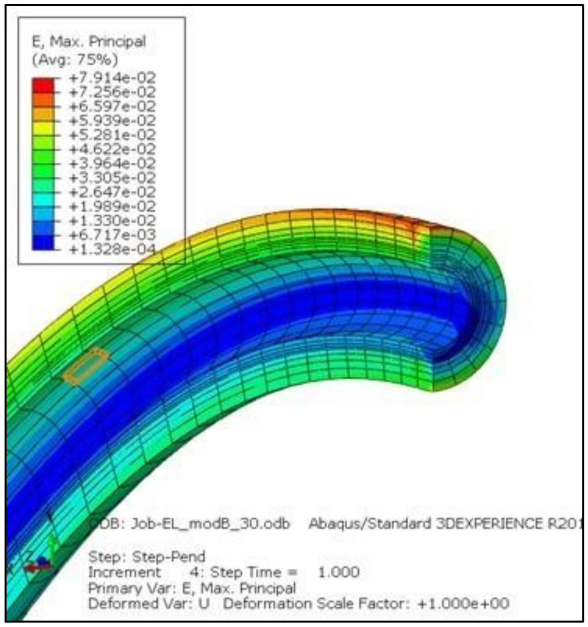

Figure 3. Strain fringe plot of two-layer tube (cross-sectioned) at a 30-degree orientation of gravity loading.

Dynamic Mechanical Analysis (DMA): This application requires the tubing to displace in response to mild, oscillatory, mechanical forces under low frequency conditions. DMA was used to simulate such conditions and to study the effect of temperature on modulus (stiffness) of the tubes. After mounting the tubing samples into a tensile fixture with a 1 cm clamp distance, temperature sweeps (-30 to 30°C @ 5°C/min) were conducted and modulus was measured using a fixed displacement of 0.1 mm at a frequency of 1 Hz. This provides low strain oscillations at a frequency representative of the motion handheld equipment is subjected to during use. Figure 4 shows the modulus of LP-1200 and Competitors A and B as a function of temperature. These results correlate well with the deflection testing. In the room temperature range, LP-1200 has slightly higher modulus relative to Competitor A. However, as temperature is lowered, the modulus of Competitor A tube increases dramatically compared to LP-1200. The more flexible LP-1200 would be able to maintain fuel pick-up more effectively at low temperature than Competitor A tubing. Competitor B has higher modulus than LP-1200 at of the all temperatures measured.

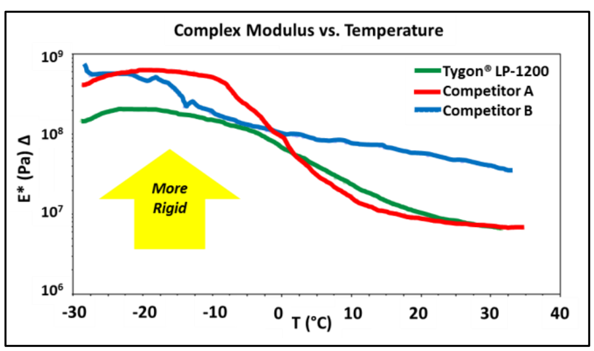

Figure 4. DMA testing on fuel tubing samples. Complex modulus of LP-1200 and Competitor A as a function of temperature. Modulus of Competitor A increases dramatically as temperature is lowered.

Thermal analysis (DSC): Using DSC, the Tg is detected as a step-like transition in the heat flow curve resulting from a change in the heat capacity. Above the Tg, a polymer will be a rubbery solid. Below the Tg, a polymer will become glassy (brittle). Generally speaking, if flexibility is required in an application, it is best to only use a material at temperatures above the Tg. These results are shown in Table 3. The samples were scanned at a rate of 10 °C/min.

Table 3. Glass transition temperatures measured using DSC.

Material	Tg (°C)
Tygon® LP-1200 (TPE jacket)	-45
Competitor A (fluoroelastomer)	-5
Competitor B (rubber)	-35

These Tg values corroborate the deflection and DMA test results explaining why the Competitor A sample's modulus increases significantly at low temperatures, while Tygon® LP-1200 better maintains its flexibility at low temperature. This has implications beyond just flexibility and fuel pick-up. Durability at low temperature is critical as well to prevent rupturing of the fuel line and maintenance of tolerance seals.

Low Temperature Bend Test (ASTM D380-12): In handheld power equipment products, the section of low permeation fuel line running between the tank and the carburetor is exposed to the outdoor environment. In addition to UV resistance, the fuel line must have the strength and durability to withstand mechanical stresses such as bending and tensile stresses that can occur during use. This is critical in order to maintain fuel line integrity and safe equipment operation. This can be a challenge at low temperature conditions since plastic materials become brittle below their glass transition temperature. A low temperature bend test is commonly used in order to assess a tube's ability to withstand mechanical shock at low temperature. Based on the ASTM D380-12 methodology, samples of each product were cooled to -50□C for 72 h and then wrapped around a 33-mm mandrel. As shown in Figure 5, Competitor A and B materials both broke in half, failing the test. Tygon® LP-1200 withstood the mechanical shock and showed no evidence of cracking or fracture, successfully passing the test.

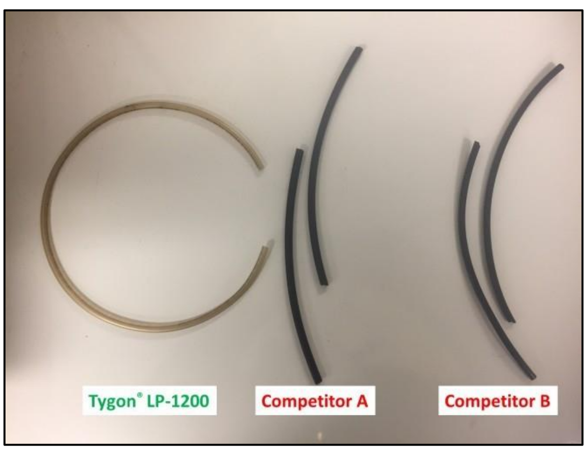

Figure 5. Test samples after low temperature bend testing. Competitors A and B both snapped in half. Tygon® LP-1200 passed the test.

This result indicates that, in the event of a mechanical shock to the fuel line, for example, if snagged on a tree branch under low temperature conditions, Tygon® LP-1200 would be more likely to withstand the event and remain an intact fuel line.

Conclusions

In conclusion, the physical properties of plastic materials are highly sensitive to conditions such as temperature and rate of deformation. Therefore, it is critical to include representative tests and conditions when selecting materials for a given application. In this evaluation, three fuel line products were assessed for relative suitability for low temperature service. Deflection, DMA, DSC, and low temperature bend testing were conducted. Under low temperature test conditions, Tygon® LP-1200 had the lowest modulus, highest deflection, and successfully passed the bend test. These results indicate that Tygon® LP-1200 has, as a result of its design and materials of construction, greater low temperature flexibility and durability and is, therefore, best suited to maintain effective fuel transfer under frigid conditions.

Abbreviations:

TPE: thermoplastic elastomer

CARB: Air Resources Board of the California Environmental Protection Agency

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