Properties and application factors to consider when choosing fluorosilicones

PERFORMANCE CHALLENGES WITH LEGACY SILICONE FORMULATIONS

The development and use of fluorosilicones in aviation applications date back to the 1960s when the U.S. Air Force found that silicone-based sealants, coatings and other materials used around gas tanks, engines and other surfaces exposed to fuels were failing prematurely.

Standard silicones, also called dimethyl silicones, have some inherent solubility and easily absorb hydrocarbon-based solvents. When this occurs, dimethyl silicones swell, weakening the silicone network with a negative impact on mechanical properties and dimensional shape.

The U.S. Air Force found that cracking and stripping of these silicones led to increased frequency of repairs and aircraft downtime. In addition, as jet aircraft began flying for extended periods at higher altitudes, the low temperatures in those environments and the presence of fuels were found to contribute to premature failure.

A material that was both resistant to solvents and could handle repeated exposure to extreme temperature ranges — from the cold of high altitudes to the heat from jet engine exhaust — was required to serve in a range of applications for aircraft at the time, as well as for next-generation platforms.

The Air Force developed a set of testing specifications (Mil-R-25988B) for fluorosilicone elastomers. These specifications outline heat aging and mechanical properties after exposure to heat and hydrocarbons. Fluorosilicones that satisfy the requirements of these specifications demonstrate that they can be exposed to hydrocarbons and temperature extremes for a longer period of time without breaking down. As a result, there is now widespread use of fluorosilicone coatings, adhesives and other materials for many functional areas of military and commercial aircraft.

THE CASE FOR FLUOROSILICONES: HOW AND WHEN TO USE THEM

The need for a fluorosilicone is determined by the operating environment and the hydrocarbon substances that fluorosilicone materials might be exposed to when the aircraft is in flight or during fueling or maintenance. When determining whether a fluorosilicone is needed, the following characteristics should be considered:

- Resistance to swelling when exposed to hydrocarbons
- Resistance to breakdown when subjected to high temperatures
- Flexibility at extreme low temperatures
- Soft and pliable to reduce stress

Today, fluorosilicones are available in a variety of forms and cure chemistries suitable for use as molding compounds, paints/coatings and one- or two-part adhesives. These give aircraft manufacturers options based on the chemical and physical requirements of the end application, as well as provide options for efficient methods for processing or applying the material.

Over time, the range of applications has expanded to include:

- Electrically conductive gap fillers to fill small cavities between aircraft surfaces
- Gels and foams for potting and encapsulating sensitive electronics to protect them from vibration and shock
- Adhesives and sealants for wire staking, bonding components and sealing joints with different coefficients of thermal expansion and attaching composite materials to aircraft exteriors
- Coatings or sheeting for the outer mold line of aircraft, fuel cells or very thin coatings on windshields and other surfaces
- Molded parts, such as gaskets and bushings, used in or near engine compartments or fuel tanks

Along with resistance to breakdown from hydrocarbon exposure and better performance in temperature extremes, there are several factors fluorosilicone users should consider when identifying the material they need (Fig. 1).

FIGURE 1: Considerations when selecting a flurosilicone

VALIDATING FLUOROSILICONE PROPERTIES

Since fluorosilicones are used in place of dimethyl silicones due to the specific requirements of aircraft operating environments, proper validation of their functional characteristics can provide valuable data for developing specific solutions. The U.S. Air Force's specification Mil-R-25988B outlines testing requirements for fluorosilicone elastomers, including heat aging and mechanical properties after exposure to heat and hydrocarbons, with attention to three specific areas: thermal stability, weight loss and swell.

THERMAL STABILITY AND WEIGHT LOSS

Thermal stability, or the resistance to mechanical breakdown of elastomers, is critical to ensure the function of material while in operation, reducing downtime for maintenance and repair.

Thermogravimetric analysis (TGA) is widely accepted to evaluate the thermal stability of materials, particularly polymeric systems such as silicones and fluorosilicones. This test allows for observing changes in mass when exposed to incremental changes in temperature above 200 °C over time.

TGA was performed on Avantor® NuSil® brand fluorosilicones to compare the rates of mass loss over time in air to demonstrate thermooxidative degradation as the temperature increased from 25 °C to 600 °C at 10 °C/min (Fig. 2). Thermooxidation is more likely to occur at the elevations at which these materials operate.

Weight loss was also measured under isothermal conditions. Using a convection oven, fluorosilicone weight loss was evaluated when the materials were exposed to high temperatures for an extended time. Cured samples were all subjected to 275 °C for one hour to evaluate weight loss at temperatures greater than 200 °C.

The following NuSil fluorosilicones were tested:

- High-temperature fluorosilicone
- Standard fluorosilicone
- Broad-operating-range fluorosilicone
- Molding fluorosilicone

TGA and weight loss results indicated that:

- All of the silicones tested lost less than 3% mass at 325 °C.
- High-temperature fluorosilicone lost less than 3% mass at 400 °C.
- High-temperature fluorosilicone lost less than 1% weight at 275 °C.

All fluorosilicones tested demonstrated excellent stability, maintaining a relatively low weight loss at 275 °C. These results indicate a very high level of thermal stability, which translates into an end-user expectation that adhesives, gaskets and other applications using these silicones will provide sustained performance and resist degradation when subjected to high-heat conditions.

SWELL TESTING

Dimethyl silicones will likely break down, swell or delaminate when exposed to fuel. As the material begins absorbing the hydrocarbon, it expands and cracks, resulting in breached seals and gaskets. Compared to dimethyl silicones, the polar nature of fluorosilicones results in decreased or very minimal swelling. In addition, it has been demonstrated that fluorosilicones will retain physical properties and dimensional shape when exposed to hydrocarbons or jet fuels.

To demonstrate the fuel resistance of fluorosilicones, a swell test was conducted on select cured samples of NuSil fluorosilicones as well as standard dimethyl silicone materials (Fig. 3). For this, the percentage of mass change in samples after being submerged in JP-8 jet fuel for seven days at 60 °C was measured. The cured samples were one-inch by one-inch (2.54 × 2.54 cm) and 0.07″ (1.78 mm) thick.

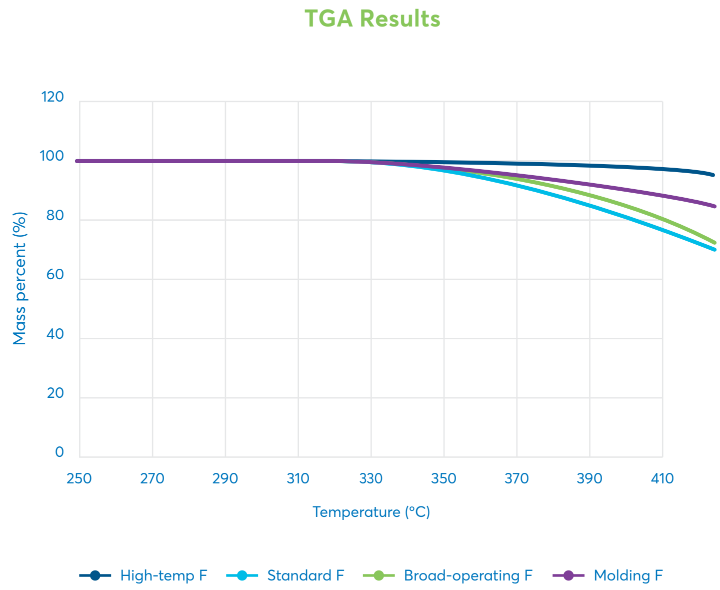

FIGURE 2: Thermogravimetric analysis (TGA) was conducted on four NuSil fluorosilicone materials. Cured samples were subjected to 275 °C for one hour to evaluate weight loss at temperatures greater than 200 °C.

The same fluorosilicones used in the TGA testing were used in the swell test, as well as two dimethyl silicones: a standard dimethyl silicone and a broad-operating-temperature dimethyl silicone.

The results showed that NuSil's fluorosilicone molding compound, high-temperature fluorosilicone adhesive and standard fluorosilicone adhesive all demonstrated less than 10% mass change, which is considered minimal when compared to dimethyl silicone materials. The fluorosilicone designed for a broad operating temperature range showed 150% less change in mass when compared to non-fluoro-containing silicones.

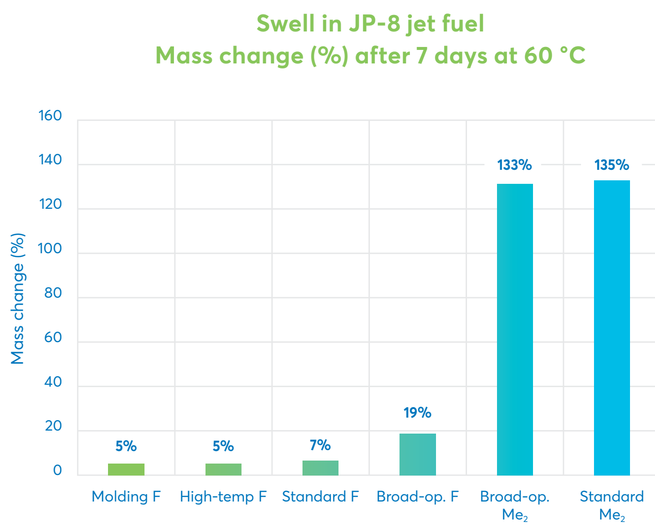

FIGURE 3: Four NuSil fluorosilicones and two dimethyl silicone materials were subjected to a swell test. All cured samples were submerged in JP-8 jet fuel for seven days at 60 °C.

NUSIL SILICONES AND FLUOROSILICONES: TRUSTED FOR OVER 40 YEARS

Built on a foundation of deep experience in fluorosilicone technology, NuSil fluorosilicones have demonstrated excellence in a range of aviation and defense applications, providing superior performance, stability and resistance to mass change when compared to standard dimethyl silicones.

NuSil fluorosilicones are available in many forms and cure chemistries. This versatility makes them ideal for diverse applications in aircraft and aerospace systems. Testing demonstrates the superior ability of NuSil fluorosilicones to resist degradation under the temperature ranges and exposure to harmful fuels and solvents that aircraft endure.

Contact NuSil® to get started

When your advanced applications require customized silicones, we're ready to supply you with the right solution you need.

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