TRELLEBORG SEALING SOLUTIONS

TRELLEBORG

Seal-Glide®

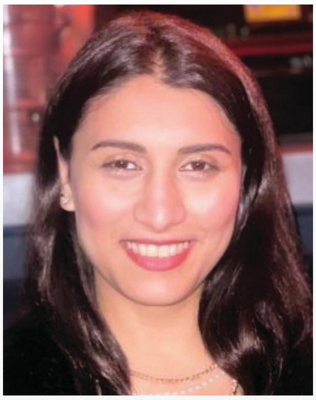
HOW SURFACE MODIFICATION OF ELASTOMERIC SEALS CAN REDUCE STICTION FORCE ON VARIOUS SURFACES

WHITEPAPER

Trelleborg in Semiconductors

Drawing on its leading position in sealing technology, Trelleborg Sealing Solutions is a pioneer in addressing and innovating solutions for evolving semiconductor applications on a global scale. A testament to its commitment to innovation, Trelleborg's groundbreaking materials specifically developed for aggressive semiconductor production conditions, along with its advanced part manufacturing capabilities, support the industry in miniaturizing and increasing the power of microchips.

Dr. Murat Gulcur
Technical Director – Semiconductor



Feyzan Durn
Senior Material Development Engineer

Dr. Maike Khosrawi
Engineer Material Research

Renate Brielmann
Engineer Material Research

Introduction

Elastomers are critical materials for sealing and damping semiconductor manufacturing applications. They prevent leakage, offer insulation, sustain pressure, maintain vacuum integrity, limit contamination, provide damping properties, and ensure the overall efficiency of semiconductor production equipment. One factor that can have a significant detrimental impact on a seal's performance is the inherent stickiness or stiction of elastomers, which means that seals tend to adhere to countersurfaces.

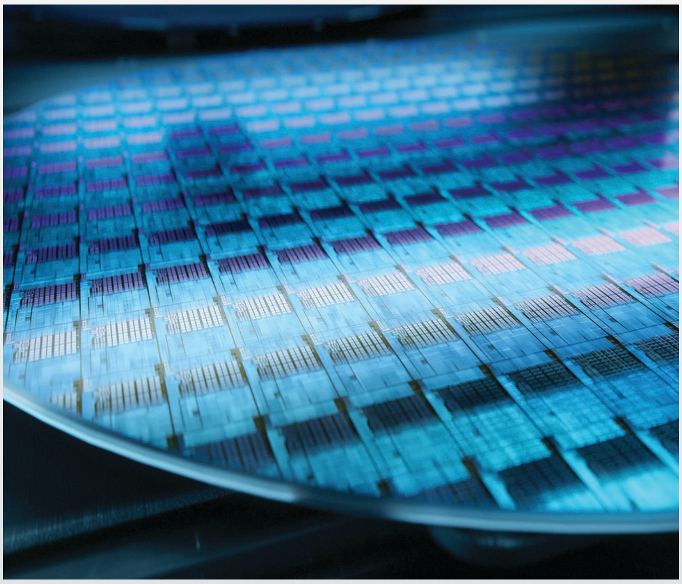
In static sealing applications, elastomer parts that stick in grooves can result in prolonged downtime to clean off seal residues from sealing surfaces and to replace seals, disrupting preventative maintenance cycles and leading to a loss in productivity. In dynamic applications, elastomers sticking onto a countersurface can prevent moving parts from working efficiently, especially after periods of rest. Therefore, it is important to minimize the stiction properties of elastomer seals to improve the productivity of semiconductor manufacturing equipment.

A change in a component's design or reselection of a sealing material can potentially solve a stiction issue. The other option is surface treatment that can mitigate the stickiness between seals and their countersurfaces. The treatments can improve the performance of seals and increases the productivity of semiconductor manufacturing tools by extending preventative maintenance cycles.

Compared to other surface treatments, such as polytetrafluoroethylene (PTFE) coating and chlorination, chemical vapor deposition is more sanitary, sustainable, and less chemically aggressive. They also apply more easily to components with complex geometries.

This whitepaper explores the effect of Trelleborg's proprietary surface treatment, Seal-Glide®, on the stiction of elastomer components against stainless steel, aluminum and quartz surfaces.

The results demonstrate that Seal-Glide® can decrease stiction force, improving the performance of elastomer parts in static and dynamic applications. In addition, this can reduce service durations for semiconductor manufacturing equipment to optimize the efficiency of semiconductor production.



Semiconductor Trends

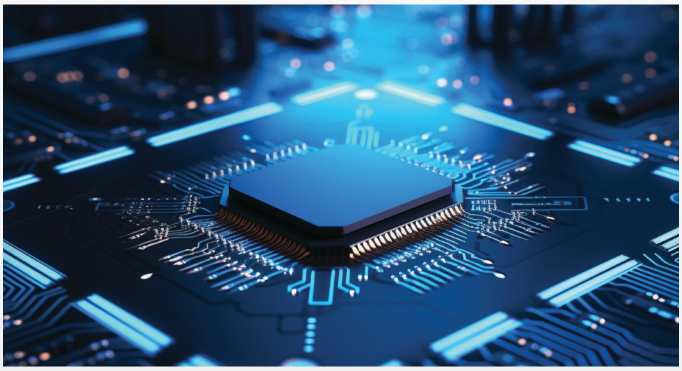
The technology behind semiconductors has evolved significantly over time, particularly around their miniaturization. In the very first integrated circuit, there were only 16 transistors with a feature size of 40 micrometers or 40,000 nanometers — about half the width of a human hair.

In 1965, Gordon Moore, co-founder of Intel, said that the number of transistors that would fit on a given area of silicon would double every two years. A few years later he revised his statement, which is now known as Moore's Law, and said that the number of transistors per integrated chip would double every 18 to 24 months — a prediction that proved true.

Today's integrated circuits have billions of transistors, and the manufacturing process is at the nanoscale. Since 2023, the most advanced technology node, or feature size, is three nanometers. That is three one-billionths of a meter.

However, processing power and data transfer speeds still need to increase further, not only for electronic devices but for recently emerging critical trends that need huge storage and processing capacity, such as autonomous driving, Artificial Intelligence, big data, the Cloud and the Internet of Things.

Semiconductor engineers are increasing processing power by creating complex architecture in three dimensions to fit more transistors in a unit area, going beyond the realms of traditional physics into quantum physics and mechanics.



Semiconductor Sealing Options

Microchips are manufactured in semiconductor fabrication plants, which are essentially giant cleanrooms with extremely expensive and specialized production equipment. Much of this equipment relies on critical sealing that can stand up to the particularly harsh conditions of fab processing.

Since Trelleborg Sealing Solutions introduced the Isolast® PureFab™ range of materials, it has emerged as a crucial problem-solving partner for the semiconductor industry. Specifically developed for deployment in the most demanding semiconductor processes.

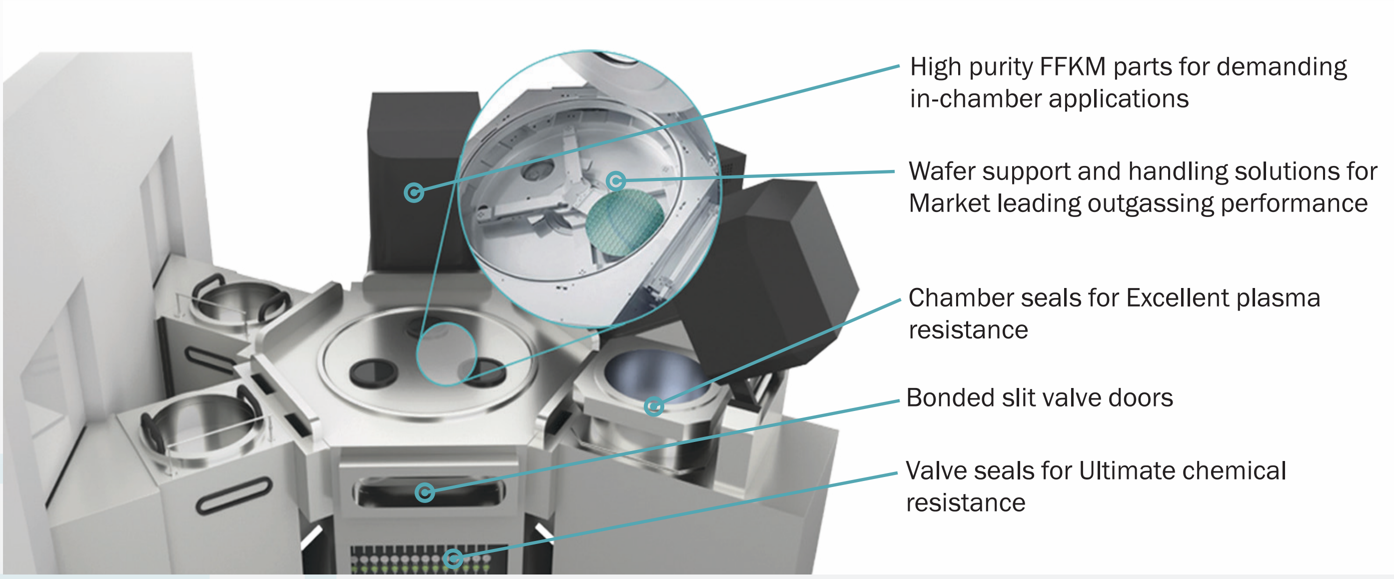


Figure 1: Typical high purity elastomer seal locations on a representative dry processing tool

Extending the life of seals in semiconductor manufacturing is key to lengthening planned maintenance intervals, which can not only reduce total cost of ownership in semiconductor fabs, but also optimize semiconductor wafer output.

Trelleborg Sealing Solutions has established itself as a longstanding supplier of critical components for cutting-edge semiconductor processes.

Isolast® PureFab™ materials boast market-leading outgassing and purity levels, while providing robust resistance against harsh plasma conditions and aggressive process chemicals.

By leveraging Trelleborg's advanced manufacturing capabilities, these advanced compounds transform into practical and high-performance sealing solutions.

In addition to commonly used sealing elements, such as elastomer O-Rings and gaskets, Trelleborg offers multicomponent sealing parts that combine various materials with Isolast® PureFab™.

This innovative technology gives design engineers unique flexibility in design, allowing the development of solutions that cannot be produced by any other manufacturing method. Addressing a niche application area, Trelleborg's products excel in damping highly critical semiconductor tools and components.

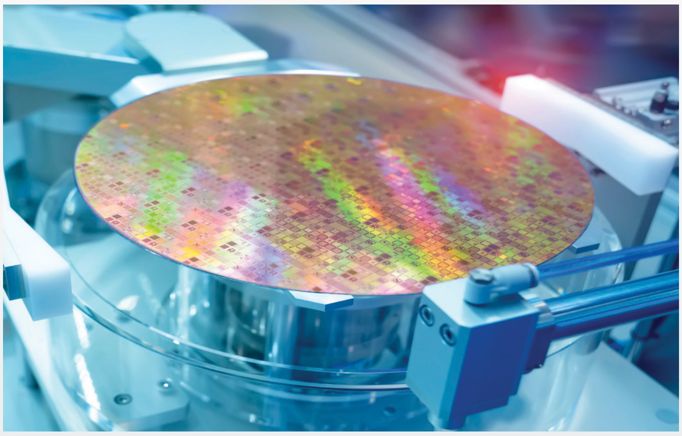
Using virtual simulation techniques, the engineering team at Trelleborg Sealing Solutions can optimize designs for specific vibration frequencies, facilitating precision in semiconductor manufacturing equipment and supporting the development of smaller node sizes.

Beyond elastomer products, Trelleborg Sealing Solutions provides a range of other essential offerings for diverse semiconductor applications, including spring-energized seals, rotary seals, advanced composites and engineered plastics.

Seal-Glide® Surface Modification

In the tests discussed in this whitepaper, the surface modification used to explore the effect on the stiction of elastomer components against countersurfaces was Seal-Glide®, a proprietary nanoscale direct surface treatment from Trelleborg Sealing Solutions.

Designed to improve the friction performance of elastomer components, Seal-Glide® application is through an innovative process, whereby a gas mixture that comprises different ion species bombards the top layer of an elastomer surface. The thickness of the modified surface is typically less than 450 nanometers, which is around 50 times thinner than conventional coatings. This means the treatment can provide major benefits without negatively affecting the properties of a seal.



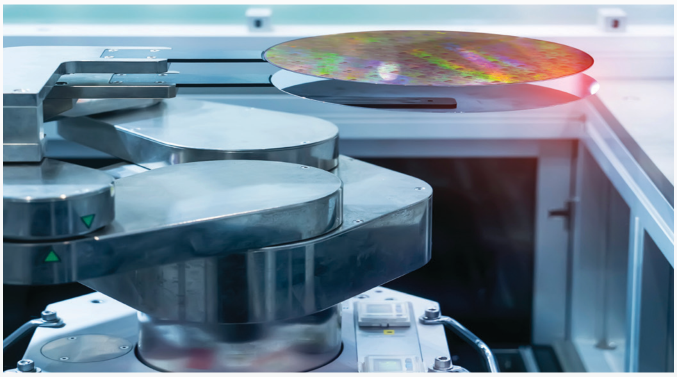
Importantly, the treatment allows the surface preparation of components with complex geometries and features, something that is impossible with lacquer-based coatings.

Test Methodology

To illustrate the effectiveness of the Seal-Glide® surface treatment in addressing stiction, two real-life scenarios were replicated in laboratory tests.

Monotonic tests: To simulate a static sealing application, an O-Ring was compressed between aluminum, stainless steel, and quartz surfaces. The test apparatus was then heated to a specific temperature for a designated duration, then cooled to room temperature. Using a tensometer, the maximum force required to separate the two plates from the O-Ring was measured and recorded as stiction force.

Cyclical tests: To reproduce dynamic applications involving repeated opening and closing throughout a seal's lifespan, an O-Ringwas compressed between stainless steel and aluminum surfaces over multiple cycles. The force needed to separate the plates from the O-Ring was recorded in 100 consecutive instances and the data statistically analyzed to obtain dynamic stiction force.



Test specimens

Test specimens consisted of four different perfluoroelastomer (FFKM) materials and one Fluoroelastomer (FKM) material, in standard AS-214 O-Ring form (Dimensions: 24.99 mm internal diameter and 3.53 mm cross section).

Sample Code	Material	Material Description
FFKM1	Isolast® PureFab™ JPF10	Fully organic compound
FFKM2	Isolast® PureFab™ JPF20	Compound with excellent resistance and performance in plasmas
FFKM3	Isolast® PureFab™ JPF21	Compound for etch, deposition and thermal processes with a superior high temperature capability
FFKM4	Isolast® PureFab™ JPF30	A high purity, translucent compound
FKM	VCT10	General purpose compound

Table 1: Test specimens

Monotonic tests

In the monotonic tests, the stiction forces for test samples in the four selected FFKM and the FKM materials were analyzed in their untreated state and after Seal-Glide® treatment to identify the difference in stiction forces.

To do this, O-Rings were positioned singly in the center of test rigs made of the following:

- 316 grade stainless steel with a surface roughness of 0.28 R_a
- 5083 grade aluminum with a surface roughness of 0.28 R_a
- Optical grade polished quartz with a surface roughness of 0.20 R_a

In one set of tests, all untreated and treated materials were conditioned in an oven at +70 °C for 20 hours. In another set of tests, untreated and treated FFKM1 and FFKM4 materials were conditioned at +200 °C for 20 hours. All samples were compressed to 10 percent of their original heights in test rigs. O-Rings were measured by squeezing the test specimens at a fixed height between the two surfaces of a rig.

The samples were then uniaxially loaded with tension. The maximum force obtained from the test, the static stiction force, is the force needed to separate the two surfaces of the rig.

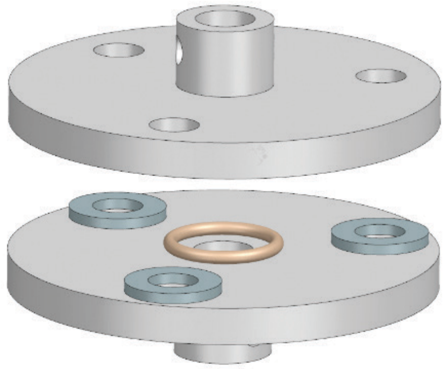


Figure 2: Schematic representation of a stiction test rig showing an O-Ring in its central testing position and the two plates and three spacers that provide the required deflection for the test.

Cyclic tests

To demonstrate the stiction performance of seals treated with Seal-Glide® in dynamic applications, cyclic tests were performed using a Zwick 1445 machine with a load capacity of **10 KN.**

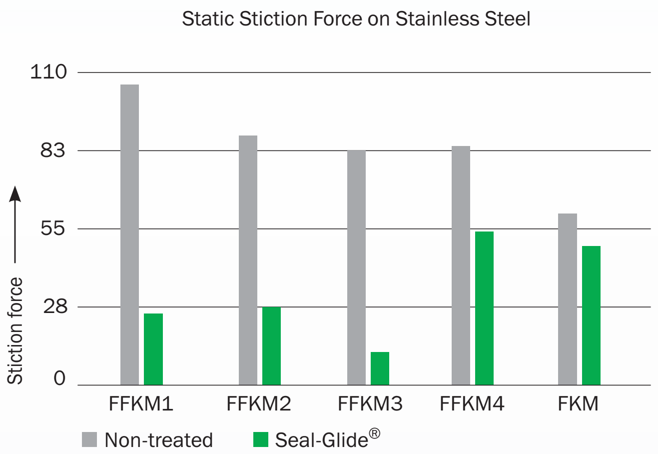
O-Rings were compressed and un-compressed 100 times at a **10 mm/min** displacement rate with a one-minute hold time. The two plates of the rig compressed the O-Ring to 10 percent of its initial height.

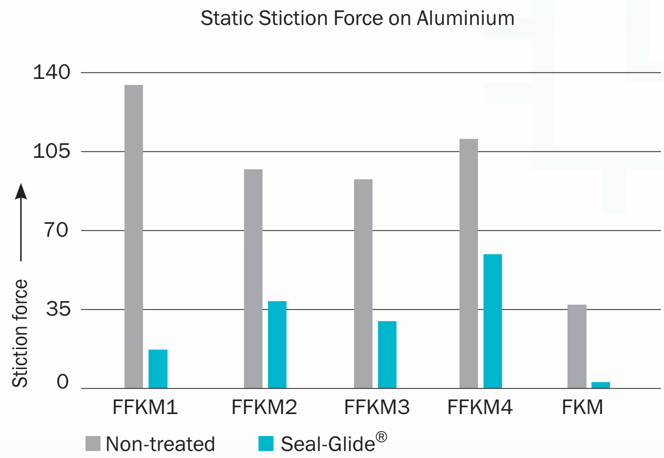
O-Rings and rigs were stored for at least one hour at +70 °C before tests started and the test temperature was kept at +70 °C during the 100 cycles. Stiction forces were measured on anodized aluminum and stainless steel surfaces for each of the untreated and treated samples.

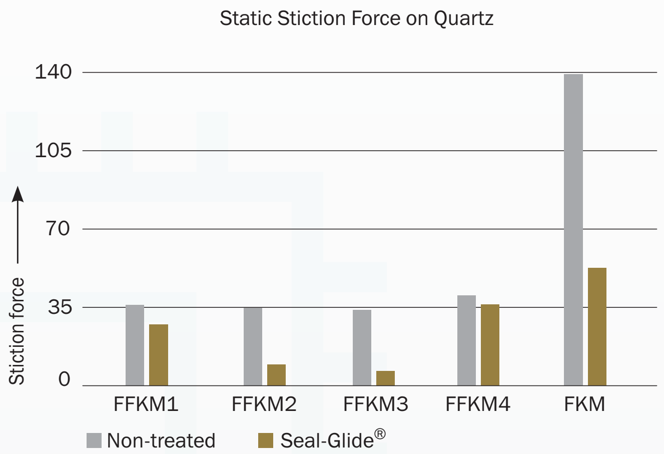
Figure 3: Test set-up for cyclic compression

Results and Discussion

Static tests







Figures 4: Stiction force comparison of Seal-Glide® treated and untreated FFKM and FKM materials on stainless steel, aluminium and quartz surfaces at +70 °C

Cyclic tests

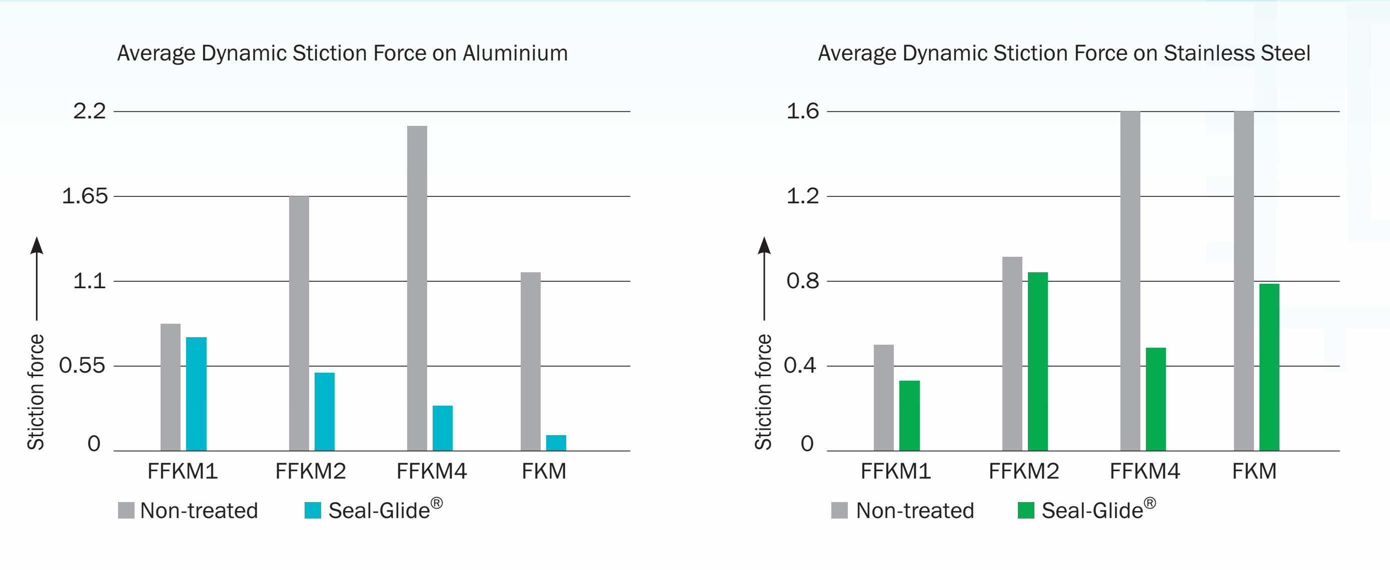


Figure 5: Dynamic stiction forces of four FFKM and one FKM materials conditioned at +70 °C and tested on aluminum and stainless steel surfaces.

Changes in stiction force over time in cyclic tests

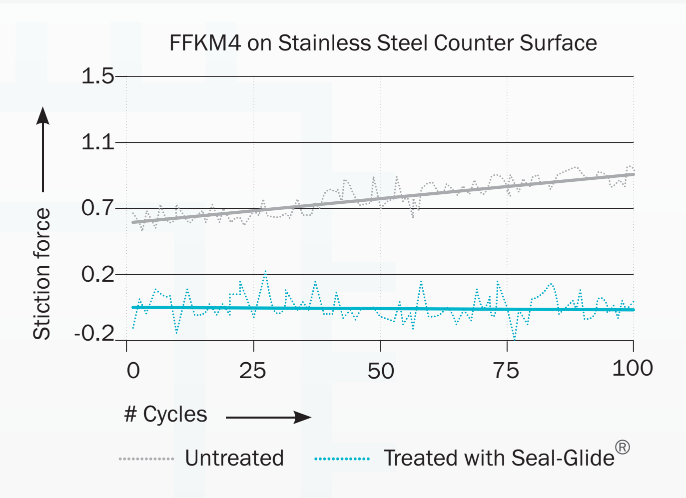


Figure 6: Change of stiction throughout the 100 cycle test. The Seal-Glide® treated sample (Turquoise line) shows no increase in stiction force while the untreated sample (Grey) shows clear increase in stiction force with the increasing number of cycles.

Observations From Test Results

- In both static and dynamic tests, stiction force values were significantly lowered by as much as 85 percent after Seal-Glide® treatment.
- Over the duration of the cyclic tests, the stiction force for the Seal-Glide® treated samples stayed stable while the stiction force for untreated samples consistently increased.
- Even without Seal-Glide® treatment, the FFKM1 material exhibited very low stiction properties in both static and dynamic applications.
- The change in stiction force is more pronounced for materials conditioned at +70 °C compared to those conditioned at +200 °C.
- Seal-Glide® treatment seemed more effective for O-Rings against aluminum surfaces when compared to O-Rings against stainless steel and quartz surfaces.

Conclusion

Stiction of sealing materials on countersurfaces is a common problem in both static and dynamic semiconductor manufacturing applications. To overcome this issue, one option is a surface modification. This has a major benefit over spray coating, as it allows successful treatment of sealing elements with complex geometries and its minimized thickness, 50 times thinner than conventional coatings, means it does not negatively affect the physical properties of a seal.

To understand the effectiveness of surface treatment in reducing and limiting stiction, Trelleborg undertook in-house developed tests using its proprietary Seal-Glide® surface treatment with a variety of its Isolast® PureFab™ FFKM materials and one FKM compound, all of which are commonly used for seals in semiconductor processing equipment.

All of the FFKM Isolast® PureFab™ range of compounds specifically developed by Trelleborg Sealing Solutions for specialist semiconductor applications exhibit low stiction properties. For applications where extremely low stiction is needed, in addition, treatment with Seal-Glide® can significantly lower stiction.

Trelleborg demonstrated that the Seal-Glide® treatment could lower stiction between the seal and the countersurface by up to 85 percent. Such a reduction can represent major benefits in the performance of semiconductor manufacturing equipment, reducing planned and unplanned maintenance, leading to a lower total cost of ownership.

As sealing performance is dependent on application criteria and sealing characteristics, the results indicate that with the variety of options available to reduce stiction, it is always best to work with an experienced sealing supplier such as Trelleborg Sealing Solutions, to specify the optimum sealing materials and surface treatments for each semiconductor equipment application.

Trelleborg is a world leader in engineered polymer solutions that seal, damp and protect critical applications in demanding environments. Its innovative solutions accelerate performance for customers in a sustainable way.

Trelleborg Sealing Solutions is a leading developer, manufacturer and supplier of precision seals, bearings and custom-molded polymer components. It focuses on meeting the most demanding needs of aerospace, automotive and general industrial customers with innovative solutions.

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